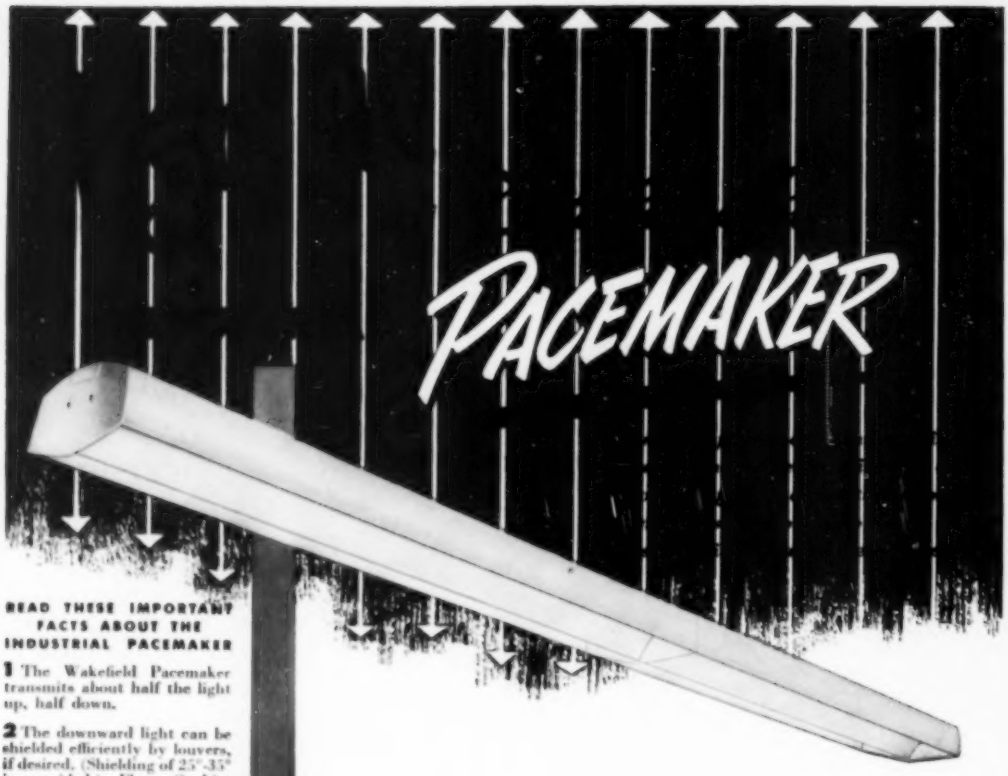
ILLUMINATING ENGINEERING

APRIL 1952

Starting F-Lamps at Low Ambient Temperatures
BCD Brightness Ratings in Lighting Practice
A Study of Large Area Acrylic Ceilings
Effects of Light on Colored Surfaces
Color Correction in Mercury Lamps
Evaluation of Visual Comfort Data
Lighting an Executive's Office

THE JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY



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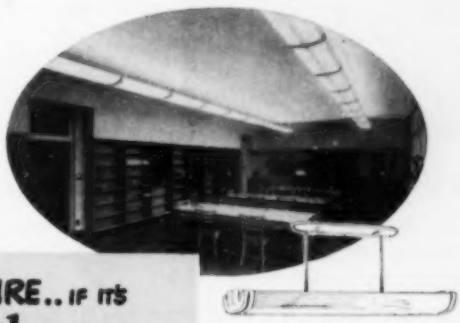

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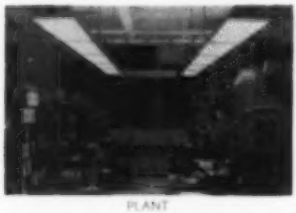

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ILLUMINATING ENGINEERING

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APRIL
1952

Vol. XLVII
No. 4

Views and Opinions—The End of an Era ... S. G. Hibben 173
A Study of Large Area Acrylic Plastic Ceilings ... E. M. Linforth 175
Lighting Data Sheet—Series XVII
Lighting a Sports Arena (20-24) ... 179
Two-Level Three-Color Lighting for an Executive's Office ... 181
Current Trends in Lighting Practice ... 182
BCD Brightness Ratings in Lighting Practice ... Sylvester K. Guth 184
The Evaluation of Visual Comfort Data ... H. L. Logan and A. W. Lange 195
Lighting Data Sheet—Series XVII
Exterior Lighting for a Factory Office Building (24-25) ... 206
Color Correction and Other Important Improvements in Mercury Lamps
H. D. Fraser and W. S. Till 207
Starting Fluorescent Lamps at Low Ambient Temperatures
R. F. Townsend and H. E. Bachman 214
Object-Color Changes from Daylight to Incandescent Filament Illumination
Harry Helson, Deane B. Judd and Martha H. Warren 221
Questions and Answers on Light Sources ... 234
Also: Empire Elegance Enhanced by Lighting, Minneapolis, Minn., 194: Jewelry Displayed by High Level Lighting, Duquesne, Pa., 205: Mercury Vapor Lighting for a Bridge, McKeesport, Pa., 213: Building Dramatized by Lighting, Worcester, Mass., 220
TELECAST—Lighting News of Current Interest ... 5A
Lighting Calendar, 7A: Books and Pamphlets, 10A: New Members, 16A
My Most Interesting Job Contest ... 2A
I.E.S. Publications ... 4A, 32A
Index to Advertisers ... 33A
Committee Personnel, 1951-1952—For latest listing refer to March 1952 issue of ILLUMINATING ENGINEERING.
National and Local Officers, 1951-1952—For latest listing refer to March 1952 issue of ILLUMINATING ENGINEERING.
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A. D. Hinckley
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Views and Opinions

The End of an Era

THE TERMINATION of the Electrical and Gas Association of New York which was publicly marked by a testimonial dinner this winter in honor of the Association's last President, Frederick S. Kinsey, brings to a close an era of unique significance in the annals of electrical and associated industries and businesses.

IMMEDIATELY following this dinner meeting, the furniture and general equipment of the Association were sold; the important records placed in storage; the Headquarters rooms in Grand Central Palace building were closed and locked, and the organization liquidated by consent of its governing Board. All this might not have rippled the deeply flowing streams of commerce nor have justified much more than a brief news mention, were it not for the influences of this Association and of its Lighting Institute upon the operations and growth of the lighting industry in the New York area especially.

THE CLOSING of the demonstration rooms might pass unnoticed, but for the fact that this headquarters meeting place in New York for many years did materially assist the spirit of cooperation and coordination, just as its influence spread to other somewhat similar demonstration and educational centers in Chicago, Kansas City and elsewhere. The educational efforts of the General Electric Company's school of lighting at Nela Park, Cleveland, which institution had previously done grand pioneering work in the coordination of lighting knowledge in that area, were undoubtedly stimulated and rejuvenated. The Chicago Lighting Institute was an early outgrowth, and on more modest scales there were numerous lighting demonstration centers and educational facilities developed under the auspices of operating utility companies or electrical distributors, as the idea spread. Even in London, Paris, Berlin and many European cities, the long-range value of the permanent lighting institute was rooted.

THE CRADLE of the Electrical Association (of 1928) was actually one of these demonstration centers, although since 1923 there had been an organization to harmonize the industry locally. In the summer of 1929 there was opened under the name of the Westinghouse Lighting Institute an exhibit headquarters that occupied the major part of the seventh floor of the Grand Central Palace building. Here was built a display center that covered almost an acre of space — 40,000 square feet — devoted to fully equipped demonstration rooms such as the following:

A modernistic entrance foyer and its adjacent loggia with formal statuary, models of some outstanding lighted monuments, busts of some famous pioneers.

A promenade with a summer terrace, the latter brightened with an electric fountain and mosaic murals of illuminated caverns and the night-time skyline of the city.

A complete art gallery with a valuable collection of paintings, this convertible also into a demonstration space to illustrate the lighting of jewels, or of the operating table in a modern hospital.

A complete school room with examples of luminous windows, overhead enclosing globes and localized blackboard lighting.

Display rooms of electrical appliances, and of the typical retail electrical store.

A miniature street with scaled street lighting posts and with bordering facades of lighted show windows and electric signs.

A completely equipped auditorium seating some two hundred people with flexible lighting fixtures of peculiar ingenuity and a completely electrified stage with preset control board, scenery, projection apparatus and sound systems and all necessary devices to hold group meetings.

A room replete with examples of electrical advertising, floodlighting and electrical specialties of various types, such as models of buildings, or the changing cycle of day and night over a city.

A complete built-in residence with living room, dining room, bedroom, bath and kitchen — each with its representative modern lighting arrangements and completely furnished.

An automotive display room showing front halves of passenger automobiles and all demonstrable varieties of headlight and signaling equipment.

A model airport completely equipped in miniature with approach and landing lights, beacons, and luminous accessories.

A full-scale model factory with motorized machine tools and flexible systems of overhead and localized lighting.

A florist shop, and several halls and alcoves in which were panel displays of collections of lamp bulbs for special services.

IN ADDITION were several handsomely furnished meeting rooms, the Director's Office with a complete control map; a large business office and, of course, other spaces for storage, the building of models, a carpenter's shop, etc.

ASSOCIATED with the design and building of this Lighting Institute were many names well known in the Industry such as F. P. Platt and Brother, the architect; Arthur Allen, the Westinghouse Vice-President who spark-plugged this installation; Ralph Neumuller, its directive head since 1929; W. A. Oglesby, Chief Engineer and Supervising Technician; Gunnison, Carlsen, Hibben and others as designers or supervisors. The construction committee consisted of well-remembered men — O'Brien, Atwater, Smith; construction was done by Clyde R. Place and wiring by Fishback and Moore.

MANY nostalgic memories center around the old Institute, and in many a lecture or demonstration meeting were sown the seeds of lighting knowledge that have grown to such healthy proportions in these two intervening decades. Hardly a night passed, but some important group held its meeting in the spectacular auditorium.

SPACE is not now available to discuss the marvels of wiring and remote control, nor such records of interior capacities as of the two main feeder circuits, (three-phase four-wire), one of one million and the other of one-half million cm! How many hundred miles of branch circuit and control wiring would be hard to estimate — in fact such a maze of electrical wiring was necessary, that specially designed partition walls had to be devised of open metal framework in order to accommodate this interlacing forest of copper.

AFTER a few years of operation as a private educational center, the Westinghouse Lighting Institute was donated to the then newly consolidated Electrical Association of New York (later in 1937, the Gas title was added to the name), and the enlarging business of that Association was carried on at these demonstration headquarters. Radiating therefrom were numerous business and social activities. Primarily in order to further the spirit of acquaintanceship and cooperation, great luncheon meetings were held in the Hotel Astor with capacity crowds that well remember the fabulous Christmas luncheons, the Thanksgiving turkey prizes and a notable list of famous speakers. Many famous guests graced the headtable in the historical ballroom, flanking such Past-Presidents as Messrs. Law, Barnes, Stephens, Bush, Youngholm, McKenna, Carpenter, O'Brien, Callahan and Kinsey.

NATURALLY after remembering the good work that the Association accomplished one wonders why it was terminated. Perhaps the reason lies in the fact that its first job of promoting the demonstration method of teaching was done, or at least an example was supplied, which should branch out further into other communities. Also, perhaps, its first efforts in promoting luncheon and social affairs, happy as these occasions were, belonged to the earlier years when the electrical business was less coordinated and in more need of acquaintanceship, fraternization at summer outings, bowling, group meetings and the like. Today's press of business, for good or evil, may for the time demand the curtailment of some of the more leisurely and gracious activities of an organization like this — or perhaps this quarter century of experience may be not solely the close of one era in this business, but also a means of laying a firmer foundation for a new era and for a more influential association in the future.

WE WILL miss the old organization. We may look back longingly on the opportunities to meet and learn and laugh together, but we may also hope that like phoenix arising from the ashes, there may be in the not too distant future a newer and better cooperative organization to carry on the work so well begun twenty-five years ago. It is with this hope in mind, that we accept the termination of the old Electrical and Gas Association with tempered regret as we look ahead to some new organization that is needed to carry on our cooperative educational activities in the mature years lying ahead.

Samuel G. Hibben

SAMUEL G. HIBBEN, *President*
Illuminating Engineering Society

Draftsmen at work under large area plastic ceiling.

A Study of Large Area Acrylic Plastic Ceilings

By E. M. LINFORTH

THE CONSTRUCTION of a new Engineering Building at the Bristol, Pennsylvania, plant of the Rohm & Haas Company has given the company's design staff an excellent opportunity to study large-area lighting based on the use of acrylic plastic diffusers. We were in a position to design and to supervise closely, throughout the building, the installation of luminous ceilings and equipment incorporating this type of material, to make a detailed evaluation of the lighting results obtained, and to assemble cost figures. It is believed the data obtained provide answers to many questions that have been raised in connection with luminous ceilings about design considerations, maintenance factors and brightness ratios involved when large areas are lighted by this high-illumination-level technique.

The studies reported herewith concern a drafting room, 108 feet by 26 feet in area, on the third floor of the building. This is the largest single room in the structure with a luminous ceiling, although acrylic plastic has been used generally as a lighting component throughout the building. In the drafting room, the ceiling consists of .100-inch-thick translucent white panels, corrugated in a 2½-inch frequency, suspended from wall to wall below continuous runs of fluorescent lamps. The plastic ceiling is 9 feet 3 inches above the floor and covers the entire 2800-square-foot area of the room. The true ceiling is 20 inches above the plastic diffusers and is faced with $\frac{3}{16}$-inch asbestos-cement

Plenum of drafting room ceiling, 1' 8" deep. Lamps, hangers for panels and sprinkler pipes are shown.

Author: Design and Fabrication Laboratory, Rohm & Haas Co., Bristol, Pa.

board, painted white. The diffusing panels rest on brake formed aluminum T-bars, hung by ¼-inch rods at 48-inch intervals. Because of the rigidity of the corrugated panels, they are supported only at the edges perpendicular to the direction of corrugation; panels are lapped one half corrugation at the unsupported edges. The T-bar supports were adapted to permit the installation of three rows of sprinkler heads, at 8-foot intervals over the room length and projecting below the luminous ceiling surface.

Lamp layout for the room consists of 189 F96T8/45W fluorescents in 63 rows of 3 lamps each, mounted 1 foot 3 inches above the corrugated plastic on 21-inch centers, and running perpendicular to the direction of corrugation. The lamps are operated at 200 ma, with a wattage per square foot of 4.5 (including auxiliaries), and 212 lumens per square foot.

Lighting Surveys

The following data were obtained in four surveys made in accordance with I.E.S. procedure using a Weston Model 614 meter. Room conditions under which the surveys were made were:

First Survey—(5/21/51)—Without luminous ceiling, after initial continuous 100 hour burning of lamps.

Second Survey—(6/12/51)—With luminous ceiling, room unfurnished, after maximum 2 hours additional operation of lamps.

Third Survey—(6/21/51)—With luminous ceiling, room completely furnished.

Fourth Survey—Conditions same as third survey, after six months of drafting room use, lamps burning approximately 12 hours per day.

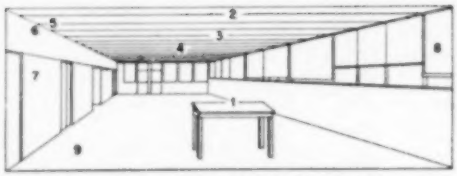
Reflection Factors:
- Walls—.52 (Upper sidewall, white acoustic plastic; lower sidewall, light green painted plaster)
- Luminous ceiling—.30
- Cavity—.79 (white painted asbestos-cement board)
- Floor—.33 (asphalt tile)

Footcandles at desk level:
- First Survey — 123
- Second Survey — 114
- Third Survey — 118
- Fourth Survey — 98

Coefficient of Utilization:
- First Survey — .58
- Second Survey — .54
- Third Survey — .56

Maintenance Factor — .82

It should be pointed out, with regard to the increase in illumination level of the third survey, made when the drafting room was furnished, over the second survey made without furnishings, that furnishings include natural-finish wood slat blinds for the large expanse of window area in the room. These were lowered during the third survey, with the result that the reflective efficiency of the window wall was increased to a point where it more than offset the loss of light trapped under drawing tables.



Sketch A — Numbered areas for which brightnesses are given in Table I below.

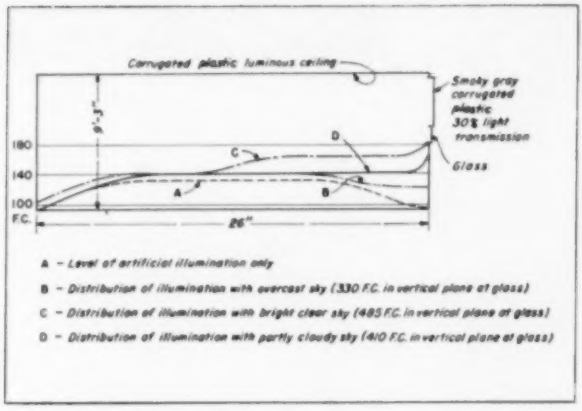
TABLE I.—Brightness in Footlamberts of the Numbered Areas of Sketch A Viewed from Area 1 at Normal Eye Level.

Area		Foot-Lamberts	Ratio to Task
1	Task (white drawing paper)	122.5	—
2	Luminous Ceiling	185.0	1.5
3	Luminous Ceiling	185.0	1.5
4	Luminous Ceiling	148.5	1.2
5	Luminous Ceiling	132.0	1.1
6	Upper Sidewall (white plaster)	70.0	1.7
7	Lower Sidewall (light green plaster)	52.5	2.3
8	Shade (wood slat)	48.0	2.5
9	Floor (asphalt tile)	24.0	5.1

The high maintenance factor after the room had been in use for six months was particularly significant to us, since it indicated that there is very little accumulation of dust on the upper surfaces of diffusing panels in a wall to wall installation. The Engineering Building adjoins the company's production facilities at the Bristol plant, which releases an average amount of industrial dirt, and the building is not air conditioned. Vision strip windows in the drafting room were open frequently during the summer months of 1951. The resulting maintenance factor, together with the relationship between wattage per square foot and average footcandle levels, establishes clearly a high order of efficiency for this luminous ceiling installation.

Brightness Survey

We were naturally interested in the brightness ratios of the installation, especially since we were dealing with a 2800-sq.-ft. luminous ceiling area, 9 ft. 3 inches above floor level, producing an average illumination level of 118 footcandles. We know that in the opinion of some lighting engineers such a high level in a room this size would result in intolerable glare. A brightness survey made on August 2, 1951 was most reassuring, as shown by the figures in Table I and Sketch A.


Corrugated plastic luminous ceiling
Simply gray corrugated plastic 30% light transmission
Glass
180
140
100
F.C.
C
D
A
B
26"
A – Level of artificial illumination only
B – Distribution of illumination with overcast sky (330 F.C. in vertical plane at glass)
C – Distribution of illumination with bright clear sky (485 F.C. in vertical plane at glass)
D – Distribution of illumination with partly cloudy sky (410 F.C. in vertical plane at glass)

Sketch B — Illumination levels from window to opposite wall under varying conditions, using the corrugated gray acrylic glazing over the vision strip.

The favorable results of the brightness surveys have been substantiated by the visual effect of the room on personnel who work at the drafting boards. As is so often the case with a properly designed luminous ceiling, personnel are hardly aware of its presence, or of any specific source of light in the room. The absence of glare and shadow in the room, particularly on the drawing tables, with resulting minimum eye fatigue, has led to favorable comment on the working conditions provided.

Cost Comparison

A cost comparison can be made between that of the luminous ceiling in the drafting room and the cost of a troffer lighting installation made by the company in an extension to its Physics Laboratory. In the latter case, because of a high noise level involved in the testing equipment of the laboratory, specifications called for a standard acoustic tile ceiling with recessed troffers. The same contractor made both installations, during the same general period of time.

Based on an average maintained illumination level of 100 footcandles in the drafting room, and 65 footcandles (with unfavorable brightness ratios) in the laboratory extension, the 54 per cent higher illumination level of the drafting room was obtained at an 18 per cent increase in installed cost per square foot of ceiling area. Installed cost for the luminous ceiling included supporting members, light source equipment, sprinkler installation, acrylic plastic sheets, and asbestos-cement board ceiling in the cavity. The asbestos-cement board was installed to improve efficiency and simplify maintenance because of the bar joist construction, with pipes and ducts overhead.

Anti-Glare Glazing

Closely related to the lighting installation in any room primarily designed for daytime use is the problem of daylight control. In true environmental lighting, the whole field of view — the walls, the ceiling, and the window areas — should be in brightness balance. Here again the drafting room of the Engineering Building gave us an opportunity to dictate a continuous fenestration design that would reduce direct glare from the sky and bring the window areas into the desired balance.

This was accomplished by installing, above operable 15-inch high vision strips of clear glass, fixed sheets of corrugated transparent gray acrylic plastic, running 3 feet 4 inches to the ceiling height of the room. The material has a white light transmission of 30 per cent, and effectively reduces sky brightness. The position of the corrugated glazing is such that, from a drafting table, it is interposed between the viewer and the sky. Nearby plant buildings, proportionately less bright, are seen through the clear glass strips below the gray panels. Sky brightness and that of the view below the horizon are thus brought into balance with the luminous ceiling, which itself makes juncture with the top of the glazed area.

The visual effect achieved with the corrugated gray glazing, of course, varies with the intensity of daylight, and is difficult to describe in measurement terms. Sketch B, however, illustrates the degree to which the glazing controls daylight, by showing the illumination level from window to opposite wall under varying conditions. It should be pointed out that this means of control of direct sky glare is so effective that it was possible to make maximum use of the floor area by facing drafting boards directly toward the window area.

Executive office with luminous ceiling of acrylic plastic pans, domed slightly upward and supported at each edge.

Laboratory and Office Lighting

In addition to the corrugated acrylic plastic luminous ceiling of the drafting room, this type of lighting has been used for individual offices, occupied by production engineers, on the second and third floors of the building, and in a large and a small office at each end of the drafting room.

Wall to wall luminous ceilings have also been installed in two executive offices, but here the ceilings are composed of formed smooth-surface acrylic plastic panels, each 32 inches by 39 inches, rather than corrugated sheets. The panels are formed into flanged pans, with bottoms domed slightly upward to insure rigidity of the .100-inch-thick material, and are supported by aluminum T-bars at each edge. Ceiling height, cavity depth, cavity treatment, and lamping are the same for all individual offices as for the drafting room.

A departure from the luminous ceiling technique was made in two laboratories, measuring 59 feet by 26 feet and 47 feet by 26 feet respectively, on the second floor. Each of these laboratories is lighted by two room-length V-shaped troughs, six feet wide. The troughs are simply continuous runs of over-lapped corrugated acrylic plastic sheets, hinge-joined to an aluminum channel at the apex of each trough. Quarter-inch hanger rods from acoustic-ceilings support the luminaires. Outer edges of the translucent white diffusing panels are attached to aluminum angles which are fastened to hanger rods in such a way that they may be unhooked and swung down on the apex hinges, for cleaning and relamping operations. The luminaires are lighted by two three-lamp banks of continuous F96T8/45W slimline fluorescent lamps.

Offices adjoining the laboratories are lighted with commercially available tubular fixtures consisting of two formed acrylic plastic semi-cylinders, the upper one clear and the lower one white translucent, enclosing two fluorescent lamps.

Lighting and maintenance studies of all installations in the Engineering Building, in addition to the results reported here in connection with the drafting room, are in progress.

Acknowledgments

The Wigton-Abbott Corporation, Plainfield, N. J., were architects for the Engineering Building. General contractor was Frank V. Warren, Inc., Philadelphia. The writer acted as consultant on architecture and lighting.

1952 National Technical Conference

Plans are underway for the 1952 National Technical Conference, I.E.S., to be held at the Edgewater Beach Hotel, Chicago, Illinois, September 8-13. Record attendance is expected this year, midwestern Chicago being conveniently accessible for most members.

The Papers Committee is currently reviewing some 35 papers and planning the Technical Sessions. A detailed program will be announced soon, and registration blanks will be sent out from Headquarters in the early Summer.

Lighting a Sports Arena

LIGHTING OBJECTIVE: To provide adequate illumination for general sports activities for both players and spectators, for televising games, and for motion picture photography.

Installation at the Palestra, University of Pennsylvania, Philadelphia, Penna.

General Information: Figure 2 shows the plan dimensions of this university gymnasium; seating capacity is 16,000. The surfaces are finished as follows:

floor	light maple	40% RF
girders	light gray-green	60% RF
walls and ceiling	buff	65% RF
seats	light gray	40% RF

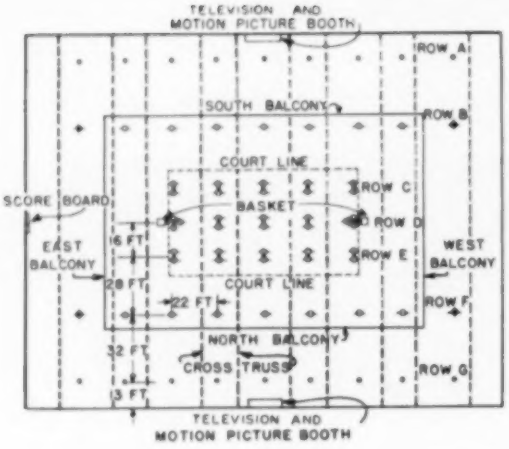
The I.E.S. recommends 30 footcandles minimum on the playing floor for spectators and players, television engineers requested 50 footcandles, and motion picture engineers (the Physical Education Department makes game training films for distribution to high schools) stipulated 100 footcandles.

Installation: One-thousand-watt PS-52 clear-bulb lamps in Westinghouse concentrating Millite luminaires are installed between beams 50 feet above the floor, spaced as indicated in Fig. 2. The beams shield the units from the view of spectators seated in the east and west balconies. All units are supported on automatic disconnect lowering hangers (Thompson Co.) for easy maintenance. Luminaires over the basketball court are located in front of the baskets so the players do not look into them when shooting from positions close to the basket. Five-hundred-watt units with glass covers are used over the side bleachers.

Thirty footcandles for basketball practice and viewing other indoor sports is provided by rows B, D and F with 1000-watt lamps.

(over)

A.I.A. File No. 31-f



Twin high-bay concentrating reflector (Westinghouse No. 1119324 without glass cover) with 1000- or 1500-watt clear lamps.

Single unit, otherwise same as above.

Medium-bay spread-distribution reflector (Westinghouse No. 1119318 without glass cover) with 1000- or 1500-watt lamp.

Medium-bay spread-distribution unit with glass cover (Westinghouse No. 119345) with 500-watt lamp.

Figure 2.

Fifty-five footcandles average after two years' operation is provided by rows B, C, D, E, and F with 1000-watt lamps burning at rated voltage (approximately 20 watts per square foot over playing floor). This meets the television requirement. (Laymen thought films made under this illumination level were good, but professional movie men disagreed.)

The 100 footcandles necessary for professional-quality motion pictures is obtained by lamping rows B, C, D, E, and F with 1500-watt lamps burned at 10 per cent overvoltage.

Brightnesses with the average 55-footcandle illumination level are as follows:

floor	24 footlamberts
girders	1½ footlamberts
ceiling	1½ footlamberts
seats	16 footlamberts

The equipment was installed by the Electro Construction Co., Philadelphia.

Lighting data submitted by George William Wagner of the Philadelphia Electric Company as an illustration of good lighting practice and to aid in the design of similar installations.

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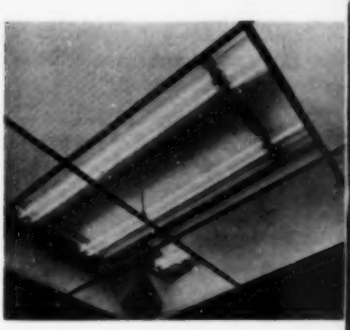

Executive's office as redecorated and re-lighted. Detail of installation shown above.

Two-Level Three-Color Lighting For an Executive's Office

THE "paneled offices of management" are often the lighting engineer's most baffling challenge. Wood paneling, and the dignity of the position combine to pose both a lighting and a psychological problem.

Two walls of this executive's office shown were originally lined with an eight-foot oak paneling and four feet of leaded glass above. The other two walls consisted of three feet of paneling plus nine feet of factory-type windows extending to the ceiling. The floor was covered with dark brown tile; the ceiling was of concrete with false beams. It could have been worse — typical areas are often lined with dark walnut, waxed, and have the inevitable glass-topped executive desk.

In the relighting plan, a luminous ceiling using corrugated acrylic plastic panels (36" x 42") was installed, supported on aluminum T-bars 24 inches below the concrete ceiling. Custom-made wiring channels locate the twelve 96-inch and twenty 72-inch lamps 21 inches above the plastic panels. The light sources are 96T8 and 72T8 slimline lamps operated at 200 ma. Lamps are mounted in pairs on 3-inch centers with adjacent pairs 24 inches apart. Each pair of lamps consists of one cool white and one warm white lamp, controlled separately by remote control touch plate switches located at the office door and beside the desk. These switches control the supply voltage to the ballasts which are mounted about 50 feet from the office.

To improve the efficiency, the valance boxes for drapery supports were built around the top of the factory windows and the leaded glass windows were covered with plywood. The plenum chamber, enclosed from the office below, is painted white.

To complete the relighting plan, the two feet of wall between the luminous ceiling and the oak paneling is oyster white to provide an intermediate brightness strip between the two. Rose-colored draperies are mounted on traverse rods, completely covering and concealing the factory-type windows. Wall to wall pale rose carpeting provides a floor of desirable reflectance value.

Results

Two-level, three-color lighting is provided by this design. With standard cool white and warm white lamps in use simultaneously, average level after 250 hours operation was 104 footcandles, with a well-diffused 130 footcandles on the desk top. With either the cool white, or warm white lamps alone in use, the illumination levels were about half these values.

Photographs and data submitted by Commercial Engineering Dept., Champion Lamp Works, Lynn, Mass.

CURRENT PRACTICE in all phases of lighting application indicates trends toward:

- combining light sources
- combining types of equipment and techniques
- combining acoustical elements with lighting techniques
- improved quality in industrial lighting
- wide acceptance of brightness engineering principles
- facilitating maintenance

Combined incandescent, fluorescent and cold cathode lighting is used in the Walgreen Cafeteria, Chicago, using a variety of techniques and equipment designs (above). Recessed louvered troffers, equipped with 96-inch T-8 and 72-inch T-8 deluxe warm white lamps operating at 120 ma provide 20 footcandles illumination on table tops. Swivel units and recessed spots use 75-watt and 200-watt filament lamps respectively. Single lengths of cold-cathode tubing are used in the coves. Walls are stained brown; ceiling is of gray acoustical material; floor is light green terazza. *Photo courtesy General Electric Co., Cleveland, Ohio.*

Low brightness, luminous indirect lighting equipment has been coordinated with furniture and decoration reflectances in this outstanding example of "brightness engineering" in the Burlington, N. J. school system. As shown above in a kindergarten room, three continuous rows of luminaires each have two 40-watt standard cool white lamps. Footlambert values of the surfaces are marked on the picture. *Photo and data courtesy of Webb Shively, F. W. Wakefield Brass Co., Philadelphia Office.*

The louverall ceiling in Halboth's Pharmacy, Brentwood, Pa., is made of 36-inch square louver sections with 137 two-lamp fluorescent industrial type reflector luminaires, which supply an average of 70 footcandles. The louver sections can be easily removed to facilitate maintenance. *Photo courtesy Duquesne Light Co., Pittsburgh, Pa.*

Acoustical baffles are combined with a luminous ceiling in this private office at the Thor Corp., Cicero, Ill. Vinylite plastic strips are mounted 9'6" over 221 square-foot area, concealing eighteen 40-watt fluorescent lamps on 3-foot centers. Average maintained level is 43 footcandles. *Photo courtesy Luminous Ceilings, Inc., Chicago, Ill.*

← Color-true light, approximating daylight, was one goal in relighting this sales area at Julius Gutman & Co., Baltimore, Md. Fluorescent and incandescent are combined in the luminaire design, which consists of spaced groups of louvered and shielded metal fluorescent units, each of four 40-watt lamp capacity, plus similar incandescent units spaced on an average between groups of three fluorescent luminaires. *Photo courtesy Metalcraft Products Co., Philadelphia, Pa.*

Current Trends in Lighting Practice

Production area of the Metals and Controls Corp. plant, Attleboro, Mass., uses light finishes throughout and equipment chosen to provide considerable upward light and shielding of lamps. Ceiling is white; walls, light green; machines, light green. Illumination level is approximately 75 footcandles. *Photo courtesy Spencer Thermostat Div., Metals & Controls Corp., Attleboro, Mass.*

BCD Brightness Ratings in Lighting Practice

By SYLVESTER K. GUTH

THE DEVELOPMENT of any concept or technique for establishing comfortable brightness relationships for interior lighting must necessarily follow a logical procedure. Such a procedure involves two basic steps including (1) the determination of the relationships among the fundamental factors which govern whether sources of brightness are comfortable or uncomfortable and (2) the extension of these relationships to actual lighting practice. The first step obviously requires a detailed laboratory study of the physical characteristics of sources of brightness and their influence upon the sensation of visual comfort. From such relationships it is possible to develop generalized conclusions which must be substantiated by, or modified in accordance with, the results of investigations conducted with actual lighting installations.

In a previous paper[1] there were presented the results of a comprehensive series of studies of the effects of sources of brightness in the visual field upon comfort and discomfort. These data, which involved casual seeing, permitted the development of the empirical equation,

$$M = \frac{B}{PF^{0.44}(Q^{-0.21} - 1.28)} \qquad (1)$$

in which

M = Index of sensation of visual comfort
B = Brightness of source, footlamberts
P = Position index
F = Adaptation brightness, footlamberts
Q = Solid angle subtended by source, steradians.

This expression includes those factors which are considered to be basic and fundamental. Other factors, such as the number of sources in the visual field and the criticalness of the visual tasks being performed, have important modifying influences upon the basic factors, but are not easily incorporated in such an equation. Therefore, they are introduced in the general concept or method of applying the empirical relationships.

In one part of the earlier investigation of the basic factors, several combinations of multiple sources were studied. An evaluation of the results led to the tentative conclusion that *a simple and practical equivalent for multiple sources of equal brightness and areas which are located above the line of vision is the total of the individual areas located at the position of the source closest to the line of vision.* In a later investigation,[2] this tentative conclusion was checked in a simulated visual environment. On the average, observed and calculated brightnesses at the borderline between comfort and discomfort or BCD brightnesses differed by only about 5 per cent.

The present paper presents the results of an investigation which was designed to determine whether the above tentative conclusion would hold for several typical lighting installations. Included are the results of an analysis leading to the development of a meaningful numerical scale for rating visual comfort. Also presented is a brief comparison of the results obtained by several investigators.

Rating Typical Lighting Installations

Experimental Conditions.—The previous experiments involved circular sources and long narrow luminous areas which are difficult to relate to the more commonly used types of lighting equipments. Furthermore, the usual fluorescent lighting installation may contain many individual units each of which presents a different perspective to an observer. Therefore, the present investigation was devised to include five combinations of units ranging in number from 4 to 21 and to determine how the individual units in each group combined to produce a sensation of brightness.

Typical 4-lamp 40-watt fluorescent units were arranged in two sizes of experimental rooms as are illustrated in Fig. 1. The units were mounted 5 feet above the eyes of the observers who viewed the rows endwise from the points marked "X." The spacing between rows was 6 feet, center to center, and between units in each row was 8 feet for arrangements A and D, 12 feet for C, and 4 feet (or continuous rows) for E. Arrangements A and B correspond to a small private office, 14 by 18 feet; arrangements C, D and E correspond to a medium sized general office or classroom, about 20 by 32 feet.

Observers.—Five observers were selected from those who were still available from the group who participated in the original investigations. They were chosen on the basis of their group perform-

A paper presented at the National Technical Conference of the Illuminating Engineering Society, August 27-30, 1951, Washington, D. C. Author: General Electric Co., Nela Park, Cleveland, Ohio.

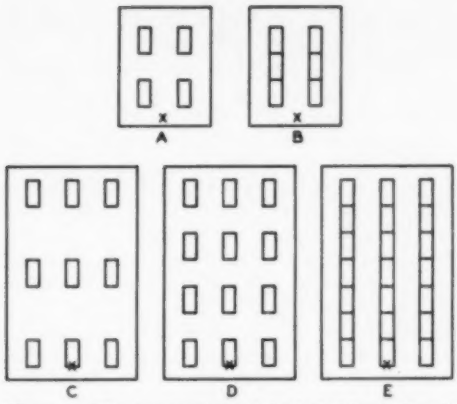

Figure 1. The arrangement of typical 4-lamp 40-watt fluorescent units used in the present investigation. The units were mounted 5 feet above the observer who was located at "X."

ance as compared with the results obtained by larger groups in the investigations of the basic factors. In order to check their subjective appraisals of brightness and to determine whether they could be considered to be a representative group, they were required to adjust the brightness of a circular source located on the horizontal line of vision until they deemed the visual sensation to be at the borderline between comfort and discomfort or the BCD sensation. This was similar to one part of the basic investigation. The source was 2.125 inches in diameter and viewed at a distance of 10 feet. At this distance the source subtended a solid angle Q of 0.000246 steradian. The adaptation brightness F was 10 footlamberts. The average BCD brightness selected by the five observers was 1330 footlamberts. The calculated average BCD brightness, using in Equation (1) M equal to 108, and appropriate values of Q and F, was 1310. This exceptionally close agreement indicated that, on the average, these observers could be considered to be representative of the larger group.

It is interesting to note that the average brightness selected by each observer was consistent with the brightnesses chosen by them in the earlier study of the effect of the size of source upon BCD brightness. Furthermore, the relative order of the observers from low to high remained unchanged. It is believed to be very necessary to select observers who, on the average, appraise brightnesses in a representative manner. If their response were not quantitatively representative, it would be impossible to check the relationships. However, throughout all the investigations of the BCD brightness relationships the observers have never been knowingly influenced in their judgment of brightness, but the smaller groups have always been carefully selected to be representative of the 50 observers used in the determination of the standard BCD brightness.

Procedure.—In the original investigations it was found that the methods involving momentary exposure of sources gave consistent and reliable results. Furthermore, when one source was located on the line of vision and viewed directly by the observers, this procedure maintained the adaptation brightness as close to that of the surrounding field as possible. Thus, the observers did not become adapted to one of the sources of brightness. The condition of momentary exposure approximates that of a worker looking up from the adaptation brightness of a large area, such as a desk, towards a source of higher brightness and appraising the sensation during the first brief period that the source or sources were in the field of view.

The comparison method was used. That is, the observers adjusted the brightness of a test source located on the horizontal line of vision so that the initial sensation received from it was the same as the initial sensation received from the particular installation being compared. At all times the line of vision was horizontal and down the room, parallel with the units. The test source was identical to the one previously described and used for checking the observers.

Since it was not feasible to maintain an adaptation brightness and to turn the fluorescent units on and off, a mechanically operated translucent plastic shield was used to expose alternately the units and the test source. This shield was close to the eyes and thus filled the greater part of the visual field. The shield was illuminated so that in each case its brightness corresponded to the brightness of a visual task having a reflectance of about 70 per cent located on a desk in the specific room. For example, in condition C, the average footcandle level was 50 footcandles for which the brightness of the plastic was adjusted to 35 footlamberts.

By this method the visual sensation of brightness from a complete lighting installation was equated to the brightness of the small circular test source. Since the original investigations upon which Equation 1 is based also involved circular sources, it is possible to calculate the index of sensation M for the test source. A similar calculation for the fluorescent units, using the sum of the individual solid angles subtended by each of the units as Q, yields a second value of M. If the two indices of sensation

agree, the proposed method of considering groups of sources can be considered valid.

The brightnesses of the units were determined from the candlepower distribution curves and the projected area of the units as viewed from the position of the observer. The value of brightness used in the equation was the average brightness weighted in accordance with the solid angle subtended by each of the units present in the visual field. Average brightnesses of well-louvered units were found to be relatively constant for a wide range of viewing angles. When the lamps could be seen, as with inadequate shielding, the brightnesses were somewhat higher. Using a weighted value of average brightness represents more accurately the brightness to which the observers are exposed. Only those units or portions of units included within a 50-degree zone about the horizontal line of vision were included in the calculations since at greater angles there is little effect. The position index P of the complete installation was determined by the source located closest to the line of vision. This is the method used in the previous investigation of a simulated visual environment and is to be preferred to the sum of the projected areas because of the considerable differences in the distances from the eye to each source.

Experimental Results.—The physical data for the typical fluorescent lighting installations illustrated in Fig. 1 are presented in the upper part of Table I. The values of solid angle Q, position index P, weighted brightness B of the units and adaptation brightness F were substituted in Equation (1) to determine the index of sensation M for each of the experimental conditions. Similarly, the physical data for the circular source (subtending a solid angle Q of 0.000246 steradian) determined its index of sensation for the corresponding condition as shown in the lower part of Table I. It is seen that the indices of sensation for each of the lighting installations and for the corresponding test source

TABLE I.—Physical data and average indices of sensation M for typical fluorescent lighting installations and single sources of brightness which were judged to produce the same visual sensation.

	Experimental Condition				
	A	B	C	D	E
I. Lighting Installations					
Solid angle Q, steradians	0.0608	0.111	0.0228	0.0547	0.130
Position index P	2.3	2.3	1.5	1.5	1.5
Weighted brightness B of units, footlamberts	450	490	560	550	570
Adaptation brightness F, footlamberts	40	70	35	50	70
Index of sensation M	74	106	84	117	226
II. Circular Test Source					
Observed brightness B, footlamberts	1570	3050	1920	3100	6950
Index of sensation M	70	106	91	125	243
Difference between indices of sensation M, per cent	4.8	0	8.3	6.4	7.0

brightness are in excellent agreement, the average difference being about 5 per cent.

From the foregoing it is seen that the general method of applying the BCD concept results in values that agree with experimentally determined indices of sensation. Similar agreement has been obtained with widely different types of luminous elements ranging from a series of small circular areas to long narrow sources.[1,2] In other words, the proposed method of combining a group of sources by adding the individual solid angles and using the position index of the sources closest to the line of vision appears to be a valid one. It is unnecessary to apply a position index to each of a group of sources. In fact, if this is done, calculations of indices of sensation for a group of sources often indicate them as being more uncomfortable than they really are. These results indicate that this method of appraising brightnesses in the visual field can be applied to actual lighting installations and that logical and meaningful results will be obtained.

Rating Sensory Appraisals

Since the BCD concept seems to be readily applicable to lighting installations, it appears desirable to develop a numerical scale that can be used for rating the visual sensation induced by sources of brightness. For such a scale to be of practical value, meaningful values should be assignable to each of a series of numbers.

Luckiesh and Holladay,[3] in their comprehensive investigation of the effects of bright light sources upon visibility, included an attempt at appraising the psycho-physiological effects of glare. They developed a scale of comfort-discomfort or "degrees of sensation" from a scarcely noticeable sensation to intolerable and painful sensations. More recently, Petherbridge and Hopkinson[4] applied four criteria ranging from just imperceptible glare to just intolerable glare. When only a few observers are involved, it is possible to agree upon a series of definitions of various degrees of comfort and discomfort. However, any particular sensation would be a matter of considerable debate among a large group of individuals. Therefore, the criterion used in our investigations of the basic factors[1] was confined chiefly to the single sensation at the borderline between comfort and discomfort. Thus, the various factors which govern whether the brightnesses in a visual environment are comfortable were related on a common basis and combined in an empirical expression such as Equation (1).

In the initial phase of the investigation a random group of 50 observers was used to determine the BCD brightness of standard test conditions

which were incorporated in later phases as a common denominator. These conditions included a circular source 1.48 inches in diameter, located on the line of vision, and viewed amid a surrounding field brightness of 10 footlamberts. At the viewing distance of 40 inches, the source subtended a solid angle of 0.0011 steradian. The individual values of brightness judged to be at the borderline between comfort and discomfort ranged from 315 to 1600 footlamberts and the geometric mean BCD brightness was 830 footlamberts. The variation among the individual observers is to be expected because of the many physiological and psychological factors which may influence the subjective appraisal of bright areas.

Since these data were obtained by a relatively large number of observers, they can be used as a basis for establishing the probable percentage of a group who can be expected to judge the brightness of a source to be at, or more comfortable than, the borderline between comfort and discomfort. An analysis of the data indicates that an approximately normal distribution was obtained from the 50 observers. Rather than develop a percentage scale in terms of brightness, it was decided to apply the general equation which relates the index of sensation M to the BCD brightness B. In the equation both the index of sensation M and the source brightness B are to the first power; thus, they are directly proportional. Therefore, M can be used to rate the combined effects of all the factors and corresponds to the "K-factor" developed by Holladay. It enables comparing various brightness conditions. Thus, for example, smaller and larger values of M indicate greater comfort or discomfort, respectively.

The data obtained with the 50 observers have been grouped into 100-footlambert ranges of BCD brightness and are presented in Table II. The average BCD brightnesses selected by the observers included within each range of brightness are shown in the second column. The index of sensation for each average value of brightness has been calculated by means of Equation (1).* In the fifth column are indicated the number of observers who established indices of sensation greater than the average value for their range of BCD brightness. These have been converted into the percentages presented in the last column. Thus, for example, the indices of sensation M for 41 of the 50 observers, or 82 per cent of the group, were greater than 70. In other words, 82 per cent of the group could be expected to find a standard source brightness of 580 footlamberts to be at or more comfortable than the borderline between comfort and discomfort.

The relationship between the probable per cent of comfortable observers (column 6) and the average index of sensation (column 4) is presented in Fig. 2. The percentages have been plotted on a normal probability integral scale. The plotted points may be represented by a straight line which indicates a normal or Gaussian distribution of the individual observed BCD brightnesses in terms of the index of sensation M. Thus, the group of 50 observers can be considered to be representative of a much larger group.

From the relationship of Fig. 2 it is possible to predict the probable per cent of a given group who would be expected to judge a specific combination of source size, position and brightness and the adaptation brightness to be at, or more comfortable than, the borderline between comfort and discomfort. For example, if, by use of Equation (1) a value of M equal to 160 is obtained for a specific combination of environmental factors, only about 10 per cent of a group could be expected to be comfortable. On the other hand, if M is about 40, 95 per cent would be expected to be comfortable.

It may be of interest to compare the probable

*The calculated values of M have been adjusted slightly since Equation (1) is based upon the geometric mean and the normal distribution is based upon the arithmetic mean.

TABLE II.—The distribution of BCD brightnesses and indices of sensation M as determined by 50 observers, illustrating the per cent of the group who would be expected to judge the brightness conditions to be at or more comfortable than the borderline between comfort and discomfort.

BCD Brightness Range	BCD Brightness Average	Number of Observers	Average Index of Sensation M	Observers selecting higher values of M Number	Observers selecting higher values of M Per Cent
300-399	342	2	41	48	96
400-499	445	6	54	44	88
500-599	580	1	70	41	82
600-699	643	5	78	38	76
700-799	760	2	92	35	70
800-899	842	9	102	29	58
900-999	951	10	115	20	40
1000-1099	1044	5	126	12	24
1100-1199	1170	2	142	8	20
1200-1299	1230	1	149	7	14
1300-1399	1327	3	160	5	10
1400-1499	1440	1	174	3	6
1500-1599	1530	2	185	1	2
1600-1699	1600	1	194	0	0

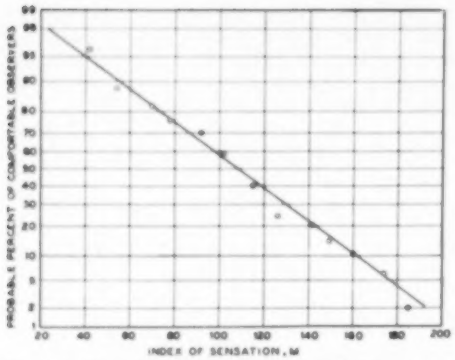

Figure 2. The relationship between the probable per cent of observers who would be expected to find that the index of sensation *M* representing a given combination of brightness conditions to be at more comfortable than the borderline between comfort and discomfort.

per cent of comfortable observers for the five lighting installations described in the first part of this paper. These are summarized in Table III.

TABLE III—Comparison of probable per cent of comfortable observers for five typical fluorescent lighting installations.

Room	A	B	C	D	E
Index of Sensation	74	106	84	117	226
Probable Per Cent of Comfortable Observers	80	52	72	41	1

The values presented in Table III are for an observer located at position "X" indicated in Fig. 1, at which the greatest sensation of brightness would be received. In general, workers would be located more towards the center of the rooms. Thus, fewer units would be in the visual field and the indices of sensation would be correspondingly less. Nevertheless, the relatively high indices of sensation obtained do indicate why some apparently comfortable lighting installations are uncomfortable to at least a few workers.

Luckiesh and Holladay[3] developed a series of *K*-factors with which they numerically related the brightness of a source to the degree of comfort or discomfort that would be experienced by an average observer. A comparison between the *K*-factors and the values of the index of sensation *M* for similar experimental conditions indicates the following approximate relationship:

$$\log M = K + 0.1 \qquad (2)$$

By means of this expression, it is possible to relate various values of *M* to several of the visual sensations defined by Luckiesh and Holladay as is shown in Table IV. The values representing the probable per cent of comfortable observers given in the last column were obtained from Fig. 2.

It is pointed out that the visual sensation indicated in the first column and the corresponding *K*-factors and values of *M* are in terms of an *average* observer and all who may view any specific brightness conditions may not receive the same sensation. However, a source brightness that is "very comfortable" for the average individual should be expected to be comfortable rather than uncomfortable for most people. It is interesting to note that the relative brightnesses corresponding to the indices of sensation *M* indicated in Table IV appear to agree generally with those found by Petherbridge and Hopkinson.[4]

Thus, sources of brightness may be evaluated either in terms of the probable number of comfortable observers or in terms of the degree of the visual sensation that may be received by the average observer. In either case, proper control of brightnesses of lighting equipments is indicated if maximal comfort is to be achieved.

Comparison with Other Researches

Space limitations do not permit too much of a detailed discussion, but it may be of interest to compare briefly the results obtained by several investigators. While differences in experimental procedures and observers and in definitions of comfort and discomfort make such a comparison difficult, there are sufficient similarities to indicate a general agreement in several respects.

Holladay, in his original investigation,[3] investigated a limited range of sizes of sources located on the line of vision. A later experiment by Holladay, reported by Luckiesh and Guth,[5] permitted modifying the original relationship by incorporating a factor which involved the displacement of a source from the line of vision. Luckiesh and Guth[1] obtained data for a wide range of sizes and various

TABLE IV.—The relationship between various degrees of visual sensation and numerical ratings applied to brightness conditions producing these sensations.

Visual Sensation	Holladay *K*-factor	Log *M*	Index of Sensation *M*	Probable Per Cent of Comfortable Observers
Very comfortable	1.5	1.6	40	95
At boundary between comfort and discomfort	1.9	2.0	100	58
Perceptibly uncomfortable	2.2	2.3	200	1
Intolerable	2.5	2.6	400	0

angular displacements. An investigation by Petherbridge and Hopkinson[4] was based upon a source located 10 degrees above the line of vision. The results obtained in these three investigations are presented in Fig. 3 for comparable experimental

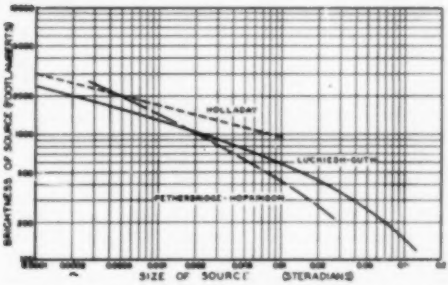

Figure 3. The relationships between the brightness and the size of a source producing comparable visual sensations as determined by three investigations for a surrounding field brightness of 10 footlamberts.

conditions which include a source located 10 degrees above the line of vision and an adaptation brightness of 10 footlamberts for approximately the same criteria of comfort. The Petherbridge-Hopkinson curve was obtained by interpolation from their graphical representations and is slightly different than the relationship indicated by their simplified empirical equation.

The curves indicate several interesting comparisons, even though the experimental techniques and the definitions of comfort and discomfort were not identical. A major difference between the techniques is that Petherbridge and Hopkinson varied the brightness of the surrounding field whereas in the Holladay and the Luckiesh-Guth investigations the brightness of the source was varied. This may be the reason for the difference between the slopes of the curves since changing the field brightness introduces an uncontrolled and variable level of adaptation. Nevertheless, the three curves indicate a straight line relationship for solid angles less than about 0.01 steradian which corresponds to about a 13-inch circular area viewed at a distance of 10 feet. The Petherbridge-Hopkinson and Luckiesh-Guth investigations both indicate that the permissible brightness for a constant visual sensation must be reduced more rapidly as the size of the source is increased beyond 0.01 steradian. The differences in the absolute brightnesses found in the three investigations illustrated in Fig. 3 are not considered to be excessive considering the different experimental procedures, visual environments, and observers used. Data obtained by Vermeulen and de Boer[6] have not been plotted in Fig. 3 because of the limited scope of their investigation. However, the relationship found by them was essentially parallel to the Luckiesh-Guth curve. It also is interesting to note that the glare rating method developed by Harrison[7] before the results of these new investigations were published generally agrees with the experimental findings.

Conclusion

The investigations and analyses described in this paper are intended to provide a better understanding of some of the aspects of comfortable brightness relationships. They illustrate that a subjective method of appraising brightnesses can be devised and that such a method provides a useful means for determining comfortable brightness relationships in actual visual environments. Furthermore, the new data indicate that the BCD concept appears to be applicable to actual lighting installations with resulting values of the index of sensation M that are logical and consistent with experience. The development of a so-called scale of probability of comfort is an attempt to assign an understandable meaning to a more or less arbitrary scale of numbers. Thus, our knowledge of the effects of the various factors which govern whether an area is visually comfortable has expanded considerably and it should be possible to apply this knowledge to modern lighting practice.

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DISCUSSION

WILLIAM G. DARLEY*: Mr. Guth and I have shared somewhat differing viewpoints on this matter and I am deeply appreciative of the opportunity which he has given me to express myself on it.

There is no question but that we should know everything that can be known about seeing; therefore, the subject study

*Consulting Engineer, Austin, Texas.

is to be commended inasmuch as it is an approach toward the assignment of quantitative values for the discomfort conditions created by brightness in the visual environment.

It seems to me, however, that a parallel study could be made by a shoe manufacturer to determine how sharp and how far into shoes nails could be permitted to extend. In my opinion, a source of glare of any degree is, in effect a pin pricking the retina. Possibly the pin is not very sharp and/or does not penetrate very deep and possibly the prick is not of long duration — but it is still something without which I would make every effort to do.

It also seems to me that there is some danger that the data will be applied more broadly than warranted. It is stated that the basic data involved casual seeing and the test method involved momentary exposure of sources. I am of the opinion that the deleterious effects of disturbing brightness ratios in the visual field become considerably more pronounced with critical tasks and as exposure time is increased. There is also some question in my mind as to whether the technique would evaluate the *distraction* created by high brightness ratios in the peripheral field — brightness ratios which, according to the data, would be completely innocuous.

In the paper it is recognized that other factors, such as the number of sources in the visual field and the criticalness of the visual tasks being performed have important modifying influences upon the basic factors and it is further stated that they are introduced in the general concept or method of applying the empirical relationships. I fail to find, however, any such method of applying the relationships advanced in the paper.

The procedure involving momentary exposure may be a good laboratory technique but it seems that also of interest would be the reaction when the sources are in the field continuously for prolonged periods.

It is stated that the present investigation was devised to include five combinations of units "and to determine how the individual units in each group combined to produce a sensation of brightness." I do not find any data bearing on the effect of the individual units in the paper.

It might be worthwhile to describe or picture the "typical 4 lamp 40 watt unit." Possibly a photometric curve would also be helpful. Considering the great diversity of such units on the market today and the equally great scarcity of really good units of this type, I hesitate to form a mental picture of a "typical unit."

I am also rather dubious of the value of the technique of determining the brightness of the unit from the candlepower distribution curve and the projected area of the unit as viewed from the position of the observer. Such a method could rate alike fixtures which had quite different maximum brightnesses. In other words, if one had a bare lamp unit with T 12 lamps on 4 inch centers its brightness would be twice as great (according to the proposed method) as that of an identical unit except with lamps on $2\frac{1}{2}$ inch centers. I doubt very much if an observer subjected to glare from the two units would agree that the brightness of the latter unit was one half that of the other.

It would have been interesting to see the results for observers seated so that they looked crosswise of the rows of fluorescent units. No matter how hard we try to prevent it there is always someone sitting so that they face at right angles to the rows of lamps; in my opinion it is for this (the worst) conditions that we should base studies, upon which it is intended that design be based.

I believe there may be a "typographical" error in the last sentence of the last paragraph of the section on *Procedure*. In two other places in the paper it is pointed out that the proposed method combined a group of sources by adding the individual solid angles whereas in the sentence in question this idea seems to be in disfavor.

It is apparent that in Table II a direct correlation does not exist between Column 3, "Number of Observers" and Column 5, "Number—Observers selecting higher values of *M*." Possibly there should be some clarification of this point.

It seems to me that the BCD method is an interesting laboratory technique but hardly applicable to practice. I certainly would not care to be responsible for the design of a lighting installation deliberately intended to cause discomfort to any percentage of the occupants in a room. In answer to this it may be said that I would base my design upon a very low Index of Sensation. This should be a good answer. On the other hand, from data which have been with us for quite some time, I am reasonably sure that any brightness in the visual field higher than the brightness of the task is deleterious; therefore in my design work for critical seeing I strive to use the lowest brightness fixtures which are otherwise acceptable.

H. L. Logan and A. W. Lange*: This paper represents another step forward in unravelling the complex problem of comfort evaluation, but it raises some questions. For example, it is our understanding that the empirical eq. (1) is valid only for a certain range of solid angles, Q, namely up to $Q = 0.1$ steradian. How then can the equation be used to prove the case in the paper for rooms B, C, D, E, all of which have a greater Q?

Secondly, the method of combining sources of varying brightness, size, and position now advocated by Mr. Guth seems inconsistent with the experimental work of his first BCD paper. Mr. Crouch's discussion following the second BCD paper pointed this out. We agree with Mr. Crouch that either the new method of handling multiple sources is questionable or the functional relationships derived from the sphere porthole (position index) tests are open to doubt.

Mr. Guth's method of combining multiple sources by obtaining a weighted average brightness, summation of individual solid angles Q, and the position index P of whichever source happens to be closest to the line of sight, does not have satisfactory experimental or logical justification. It cannot be justified by his italicized conclusion for equal Brightness B, equal Q source combination, and it does not appear to have been actually checked in the simulated visual environment discussed in Mr. Guth's paper of February 1951.

We cannot check the Simulated Visual Environment exposition of the February 1951 paper. Firstly, if the room is a 40′ x 20′ x 11′ C.H. room having continuous runs of 8′ lamps, an observer at one end will find an angle between himself and the element midpoints such that position indices in Mr. Guth's February 1951 paper Table II will be 6 instead of 3.4, 2.8 instead of 2.1, 2 instead of 1.7 and 1.7 instead of 1.5. Therefore, the results and conclusions shown from this data cannot to our satisfaction justify the method Mr. Guth advocates for multiple sources.

On the other hand, the section on Simulated Visual Environment can be used to experimentally confirm the Logan-Lange method of considering sources and positions individually, to wit:

*Holophane Co., New York, N. Y.

Data from Table III, p. 71, Illuminating Engineering February 1951.

	B	Q	P (to actual center of run)	$\frac{B}{P}$	Q' when all $B' = 455$
Left Row	1000	.118	2.2	455	.118
Center Row	800	.152	2.3	348	.084
Right Row	1000	.118	2.2	455	.118
				Total Q =	.320

at $F = 15$ Ft-L and $Q = .32$, BCD (B) = about 415 Ft-L.

This is quite close to the 455 Ft-L and gives a reasonable check.

In this investigation of simulated visual environments the results are BCD values of brightness, and the calculated (or graphically located by our method) BCD values are to check the experimental values for confirmation of, in this instance, a method of combining sources.

In the present paper Mr. Guth omits certain sources from his calculation which would actually be in the field of view of a standard observer. For example in room E the two sources of $B = 557$ Ft-L are omitted since Mr. Guth feels that they will have little effect. Yet they are in the field of view, and have a very large solid angle Q which will have a serious effect on the calculations by Mr. Guth's method. In his arithmetic summation of solid angle Q's he is ignoring the two largest single solid angles in the installation! If they were used the comfort results would appear very different.

In view of the doubts concerning use of Eq. (1) beyond its range, the lack of justification for the proposed method of combining sources and the omission of the largest solid angle Q from the calculations, we do not feel that the paper proves the validity of the "averaging" method.

As further evidence of this, we have applied the rating method described in this latest paper of Mr. Guth's as follows:

Example 1. Consider the case where there are two light sources in the field of view so located that one has a position factor of 3 and the other of 10. Give the first a brightness (B) of 300 footlamberts, with a Q of 1, and the second a B of 1000, with a $Q = 1$.

A. The method of the authors.

Applying Mr. Guth's position factors:—

$$B = \frac{1000}{10} = 100; \text{ also, } B = \frac{300}{3} = 100.$$

Therefore, using the method inherent in Mr. Guth's position index experiments, the equivalent glare brightness on the line of sight, of these two off-the-line sources, is a hypothetical course of 100 footlamberts brightness with a Q of 2.

B. Solving the same problem by Mr. Guth's latest device of "averaging" brightnesses which, as far as we know, is not supported by equally good experimental evidence, we get the following results.

$$B_{av.} = \frac{BQ + BQ}{Q + Q} = \frac{1000 \times 1 + 300 \times 1}{1 + 1} = 650.$$

As the 300 footlambert brightness is the nearest to the line of sight, and has a position factor of 3, Mr. Guth's new method requires the application of this position factor to the averaged brightness of 650; giving a substitute for the preceding "on-the-line-equivalent" of the two off-the-line sources, of $B = 217$ and $Q = 2$. By the first method the on-the-line-equivalent is $B = 100$ when $Q = 2$, so it is evident that the Guth "averaging" process gives a value that in terms of the first method is an off-the-line-equivalent (and that apparently contradicts his position index data).

Mr. Guth's work with position factors has proved that an off-axis equivalent will always be higher than an on-axis equivalent. Therefore the application of what in effect is an off-axis equivalent to a curve based upon on-axis situations is liable to result in more severe discomfort predictions than the experimental data will support.

This is borne out in the above example where Mr. Guth's new appraisal method would require a discomfort prediction based on a source over twice as bright as the on-the-line equivalent.

It is also well illustrated when we apply the Guth method to the case discussed in our paper, "The Evaluation of Visual Comfort Data," as follows:—

Example 2.

B	Q	$B \times Q$
1200	0.432	518
850	0.400	340
600	0.100	60
525	0.296	155
500	0.220	110
450	0.084	38
400	0.096	38
300	0.080	24
	Sum of Q's 1.708	Sum of BQ's 1283

Therefore, $B_{av.} = \frac{1283}{1.708} = 752$. The Guth method requires this to be divided by the position factor nearest to the line of sight, namely 1.4. This gives an off-axis equivalent of 543 for B, and 1.71 for Q; instead of the on-axis equivalent of 200 footlamberts, with $Q = 1.33$, arrived at by treating each light source individually in the same fashion as they were treated in the experimental work by which the position factors were determined by Mr. Guth.

This particular example is taken from an actual field case in which the management reported no complaints on the part of the employees; with the comfort prediction being 75 per cent, by the method described in our paper. Treating this same example by the Guth method of appraisal, as above, we arrive at a BCD brightness of 225 footlamberts, from the Visual Comfort Chart in our paper; therefore on this basis the glare situation would be assessed at 240 per cent of BCD. This gives a comfort prediction of zero. In short, *all employees* should be uncomfortable!

We have reasoned theoretically that true threshold curves would go through points of equal response and could therefore be employed to transpose and combine sources. There is some experimental evidence to support this cited in our paper. On the other hand, Mr. Guth's one experiment with his five observers fails to confirm this, and in order to make his comfort computation agree with his observers' judgments he finds it necessary to, so to speak, disregard all the position factors except the one nearest the line of sight; but again, this same process applied to the case cited above gives a definitely erroneous result.

Apparently, either the Guth threshold curves are not true threshold curves, or an integrating factor, that has not been indicated by any previous work, should be applied to values taken from these curves when it is desired to transpose and combine sources.

We have decided, for the time being, that as the weight of logic and of such evidence as exists, is against the "averaging" method and is in favor of the method of combining and transposing glare sources into an "on-the-line-equivalent," we should direct our efforts towards reducing whatever chances of error may lie in this process. It is evident

that the degree of possible error when using the transposition and combination process employed in our paper will be a minimum when an equivalent brightness is used in the summation process that is truly intermediate to the brightnesses being equated. This is because the operator will then have to move right or left, parallel to the adaptation level threshold on the visual comfort chart, the shortest possible distance. We therefore recommend that value to be adopted in practice.

JOHN C. SARATINI*: Based on the data and formula given in this paper it would appear that bare lamp installations per se need not be ruled as uncomfortable. Calculations which we have made using this formula (1) have shown an index of "Sensation of Visual Comfort" for a low brightness bare lamp, mounted against a white ceiling, installation, which is more comfortable than a conventional troffer type installation on the same illumination basis.

Practically, this theoretical condition can be compared by viewing and working under a bare tube cold cathode installation as against a troffer type job.

GEORGE J. TAYLOR**: Will wonders ever cease? A scientist has written a paper that not only the average person can understand but has practical value as well. The opening paragraph deserves high praise for the two basic steps suggested. The first step is the relationship of fundamental factors which determine comfortable or uncomfortable conditions. The second step is the extension of step one to actual lighting practice.

When it comes to selecting comfortable lighting against uncomfortable lighting by merely looking at an installation we are in trouble. This is true even among members of our own society. To overcome this shortcoming we have proposed I.E.S. recommended practices brightness ratios for lighting installations. Nothing wrong with that but it just does not seem to click with those who specify and buy lighting. Some pretty horrible examples of this appear in magazine articles almost every day — IE not excluded. If consumers constantly see these installations in print is it any wonder why uncomfortable lighting installations are overwhelmingly in the majority?

Because our knowledge, or better lack of knowledge, on comfort of seeing we talk about controlled zonal brightnesses and varying degrees of shielding light sources. Nothing wrong with this either except that much of it is guess work. It's about time we stopped guessing and when we do we will stop confusing people.

We have no common understanding among ourselves as to what constitutes comfort of seeing. If we do then we have failed to pass it on to the specifiers and buyers of lighting. Until they understand us, we will see poor lighting installed in high percentages as we are now experiencing.

Our experiences with the Harrison-Meaker method of determining or rating the comfort of lighting systems have been gratifying. Hundreds of people in the so-called consumer bracket have listened to this story on comfort and it has been of material help in guiding them toward better lighting systems. It appears to me that Mr. Guth has expanded and simplified the method of rating a lighting system. His Figure 2 proposes a method which tells us exactly what to expect as far as people and their comfort of seeing is concerned. Never mind what is involved in terms of computations from empirical formulas. Let our society scientists fight among themselves on this point. But for the sake of our industry let us work for some common-ground basis with our *users* of lighting so that they agree with and understand our reasoning on comfort of seeing. In other words, let us be scientific but by all means, practical. The author seems to have struck this necessary happy medium.

SYLVESTER K. GUTH*: I do not believe that Mr. Darley and I are very far apart in our beliefs that quality of lighting is of paramount importance in lighting design. Unless a lighting installation is comfortable, the footcandles on the task cannot accomplish their desired purpose. Investigations of the relative importance of the various factors which influence comfort and discomfort must be determined in terms of averages. However, the direct application of average data would mean that only half of a given group would be expected to be comfortable. Obviously, it is necessary to consider the more sensitive individuals and to base lighting design on a lower index of sensation so that everyone will be comfortable. This has been emphasized in all of the papers dealing with BCD relationships.

In the second BCD paper[1] data were presented to illustrate the permissible brightnesses of sources which were just barely distracting when the observers were performing a critical visual task. The results indicated that, when critical seeing is involved, and sources are exposed to view continuously, the brightness which produces a sensation of distraction is about 60 per cent of the BCD brightness. It also was found that the effect of displacing sources from the line of vision was different for the conditions of critical and casual seeing. Relatively lower brightnesses are permissible for critical seeing than for casual seeing when the sources are located within about 20 degrees of the line of vision. When the sources are at greater distances from the line of vision, the reverse is true. These results are difficult to incorporate in a formula, since they require a certain amount of judgment on the part of the lighting designer. However, it seems that the data do provide a basis for determining an additional factor of safety depending upon the visual requirements made of the workers in any particular area. Similarly, a number of sources in the visual field must be converted by some means into a single equivalent source so that a value of the solid angle can be used in the BCD equation. It does not seem necessary to determine the effect of each source of a group if it is desired to know what the total sensation will be. In the present paper are presented further data regarding a method for accomplishing this and illustrating the close agreement between observed and calculated values of probable comfort ratings.

The investigation of so-called typical fluorescent lighting units was not designed to prove that the particular units were satisfactory or unsatisfactory on a comfort basis. Its purpose was to obtain data for configurations and luminous areas commonly used in lighting practice and to extend the earlier work that was confined to circular and linear sources.

The question of non-uniform brightness patterns is important and additional investigations are planned to cover this point. However, a large number of appraisals have indicated that a considerable non-uniformity of brightness is given approximately the same rating as a source of the same area and equal average brightness when both sources are located off the line of vision. Observers do not seem to be particularly aware of a non-uniform brightness pattern unless it is viewed almost directly. They may not like the

*Colonial Neon Co., North Bergen, N. J.

**Supervisory Lighting Engineer, Day Brite Lighting, Inc., New York City.

*Author.

brightness pattern, but every effort has been made to exclude this psychological factor from the BCD investigations. Its omission is not intended to minimize its importance.

I agree that the judgment of comfort should be made from the most unfavorable position and the studies described in the present paper did this. Endwise viewing included a larger solid angle within the 50-degree zone and involved a lower position index than would have been obtained with crosswise viewing. The average brightnesses of the particular units used were approximately the same in either case.

There is no typographical error as indicated by Mr. Darley. The sentence in question re-emphasizes that solid angles rather than projected areas are used in the final BCD calculations.

Space limitations did not permit a complete discussion of the development of Table II. The number of observers selecting higher values of M (column 5) was obtained from the individual values determined by each observer and is not directly related to the values in the third column. For example, in the case of the 1300-1399 range, two of the observers selected values of M higher than 160 (the average for the group) and are included in that line of column 5. The other observer, selecting a lower value of M was included in the group that selected an M of at least 149. A further complicating factor was the slight difference between the geometric and arithmetic means as indicated by the footnote. The relationship between the probable per cent of comfortable observers and the index of sensation M has been checked mathematically and graphically.

A number of the questions raised by Messrs. Logan and Lange seem to indicate that they are not completely familiar with the earlier BCD papers.[1, 2]

(1) The empirical equation was determined from data on sources from 0.0001 to 0.13 steradian. Therefore, it is valid for a range beyond 0.01 steradian and can be applied to all of the experimental rooms.

(2) The method of combining sources as described in the present paper was first suggested in the original BCD paper[2] in the second column on page 664. Several methods of combining sources have been tried. The present method while perhaps not fully explainable, does seem to give results which can be experimentally verified.

(3) The suggested method for adding sources was checked in the simulated visual environment and is discussed in the February 1951 paper.[1] Reference is made to Table II of that paper and the accompanying discussion.

(4) I suggest that they check their calculations of the angles and position indices to the midpoints of the elements. For example, in the case of Element 4, the center is 7 feet above the horizontal line of vision and 12 feet in front of the observer. These are the values of V and E, respectively, used to determine the position index P. Calculating, V/E is equal to 0.583 and the corresponding position index P is 3.4, the same as the published value. The other position indices can be checked in the same manner. It seems to me that the results and conclusions derived from these data do illustrate the possibility of the suggested method for multiple sources.

(5) Their method of combining sources is an interesting one but requires a detailed analysis. This is being submitted as one of the discussions of their recent paper[3] and will appear elsewhere. It should not be surprising that two methods of combining sources should check in some cases. My calculations for their second example indicate that the installation is about average BCD and not as uncomfortable as they indicate. The fact that no complaints have been received for this specific installation could mean that no one is sitting at the worst possible position from which the appraisal was made, or that the occupants are less sensitive to brightness.

(6) In the suggested method I have included those sources and portions of sources that are located within a 50-degree zone about the horizontal line of vision. Various investigators have suggested that the important zone extends no more than 30 or 40 degrees. It seems that 50 degrees pretty well includes the sources of brightness which contribute most to the visual sensation of comfort or discomfort. If the line of vision normally would be well above the horizontal, these closer and larger sources obviously would have to be included.

(7) I have no experimental data which would enable me to combine two sources that are widely separated. I consider such an example as being an unjustifiable extrapolation of our work. The investigations have generally been confined to groups of sources which were arranged in regular patterns and relatively close spacing as is usually found in lighting practice. I would like to remind Messrs. Logan and Lange that my papers have been reports of extensive investigations. I believe that the conclusions presented have been conservative. Any extension that others may desire to make is their own responsibility. If the experimental results do not agree with such extensions and extrapolations, I do not believe that the data should be blamed.

(8) The position index P seems to be causing a considerable amount of confusion. It must be remembered that the values of P are relative brightnesses of a *single* source located anywhere in the visual field that will produce a BCD sensation. The values were not intended to be used for determining the relative sensation induced by each of a group of sources that are simultaneously present in the visual field. Furthermore, our results have indicated that indices of sensation M are not directly additive. They may be calculated for each source in a group and will indicate the sensation each would induce as an individual source. However, the values of M will give no indication of how much each source contributes to the total sensation induced by the group. To provide information for the latter would require an investigation of every possible arrangement of lighting equipments that is used in practice. Similarly, the BCD curves are for single sources. Therefore, any method of combining sources must be an empirical one that agrees with experience and can be related to available data. My published results indicate that calculated and experimentally determined values are in excellent agreement when my suggested method of combining sources is used. It seems to me that any other method should be checked with the various combinations of BCD data that are available.

With reference to Mr. Sabatini's comment regarding bare fluorescent lamps, several calculations that I have made seem to indicate that such installations (on an endwise viewing basis) will be uncomfortable for most of the occupants of a room. Typical installations for 30 to 50 footcandles require a considerable number of lamps. Thus, the total solid angle subtended by the lamps becomes sizable. The simulated visual environment described in an earlier paper[1] is an approximation of a bare lamp installation. In this example it was found that a lamp brightness of about 500 footlamberts was at the borderline between comfort and discomfort for the average observer. In order to be comfortable for at least 90 per cent of the observers, the brightness would have to be reduced to about 250 footlamberts. This is considerably less than that of a typical low brightness lamp. It seems to me that it is imperative that all of the factors of size, brightness and position of source and the adaptation

brightness be adjusted so that an installation will be comfortable for all who may view it, regardless of what the sources may be.

Mr. Taylor is very flattering. My hope has been that the BCD data will add to our knowledge and enable us to provide the utmost in visual comfort. The best mathematical technique that can be used to determine the probable degree of visual comfort of a lighting installation remains to be developed. Several have been suggested. We hope the final one will be simple, practical, understandable, and usable.

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3. The Evaluation of Visual Comfort Data. H. L. Logan and A. W. Lange, page 195 this issue.

Empire Elegance Enhanced by Lighting

The colorfully decorated Cardinal Room at the Curtis Hotel in Minneapolis is made even more attractive by the lighting installation. Under the perimeter spots and the orchestra spots the illumination level is four footcandles at table level, and under the center cove eight footcandles. The center cove has 26 luminaires, each equipped with two 40-watt fluorescent lamps placed end to end. There are 56 units in the perimeter cove, also containing two 40-watt lamps. Recessed under the perimeter cove are 31 square units with 75-watt filament lamps. The ten spots over the orchestra have 150-watt filament lamps. A bullet-type swivel unit, added as an after-thought, is mounted inside the center cove for spotlighting the speaker or entertainers. The colors of the decor are: white ceiling, pink center cove, cream walls, with dark red perimeter cove, dado and panels at each side of the orchestra. ***Photo courtesy of General Electric Co., Nela Park, Cleveland, Ohio.***

The Evaluation of Visual Comfort Data

By H. L. LOGAN
A. W. LANGE

This paper attempts a workable correlation of Holladay's, Luckiesh and Guth's, Harrison's, Moon and Spencer's and Petherbridge and Hopkinson's work on visual comfort: adds original data derived from measurements in 135 natural fields of view; demonstrates a solution that satisfies the data, and the theoretical considerations that also have to be satisfied; and concludes with a description of the procedure required to arrive at a comfort evaluation of an existing visual situation, or a comfort evaluation prediction of a planned situation. The evaluation takes the form of the percentage by which, for example, an artificial lighting job will be below or above the comfort-discomfort threshold for the conditions obtaining in the job. Finally, this percentage is correlated with the percentage of observers that may find the job comfortable or uncomfortable.

THE GOAL of the lighting engineer, stated in broad terms, is to provide such illumination patterns for all the needs of mankind, that desired, pre-determined responses will be elicited from observers. These responses are various, depending upon which aspect of the total response is to be emphasized. These aspects include, among others, rate of visual performance, accuracy, and comfort. This discussion will be confined to one aspect of comfort; vis., visual comfort.

The BCD Thresholds

The minimum quantity of light that can be perceived — the threshold — can be measured. The other end of the scale — the quantity of light to which the eye is intolerant, can also be measured: but the various degrees of response between minimal perception and intolerance are not so obvious.

Thresholds of visual comfort-discomfort have to be established by definition. Other visual thresholds provide satisfactory precedents, and following these precedents thresholds of visual comfort-discomfort become those visual conditions that will be found comfortable by half of a group of observers, and uncomfortable by the other half. In other words there will be an even split in the responses.

These thresholds are referred to as BCD thresholds, or the "brightness comfort-discomfort" thresholds.

The available data as to their actual location are generally considered conflicting. As each investigator used different and small groups of observers, different procedures, and different criteria, this was to be expected. Also, the range of sizes of sources, and of adaptation levels, varies with the different experimenters and in total is small.

The formulae[1] expressing the results of the best known investigations seem to differ considerably.

Nevertheless, if the data of these investigators are plotted together for purposes of analytical comparison, in the manner shown in Fig. 1, the curves are seen to show general similarity in slope and, except for the Harrison curves, similarity in location. Even these latter curves, as will be shown later, are probably not in true disagreement.

COMPARISON OF FORMULAE FOR THRESHOLD CURVES

Holladay	Glare Constant $= \dfrac{B^{3.3}\,Q^{0.83}}{F}$
Harrison	" " $= \dfrac{B^{3.3}\,Q^{1.7}}{F}$
Guth	" " $= \dfrac{B^{2.27}\,Q^{0.682}}{F}$
Petherbridge and Hopkinson	" " $= \dfrac{B^{1.6}\,Q^{0.8}}{F}$
Moon and Spencer	$\dfrac{B}{F} = \dfrac{\left(\frac{B}{F}\right)_{\infty}}{Q}\,(0.00874 + Q^{0.5})^2$

A paper presented at the National Technical Conference of the Illuminating Engineering Society, August 27-30, 1951, Washington, D. C. Authors: Holophane Company, Inc., New York, N. Y.

[1]The Moon-Spencer formula is in different terms to the others and expresses the shape of curve through Holladay's experimental comfort-discomfort threshold points that is required by the Moon-Spencer photochemical theory of vision.

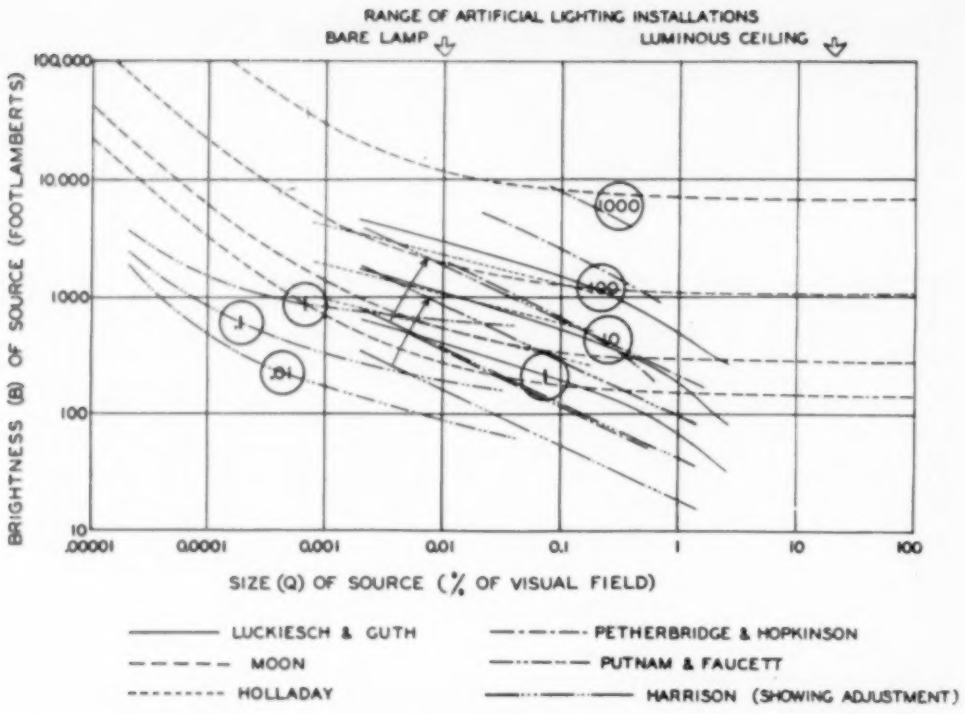

Figure 1. Summary of visual comfort evaluation data. The encircled numerals are footlamberts and locate the various approximations of comfort-discomfort thresholds for the adaptation levels shown.

BCD Curves

Fig. 1 shows curves of equal response (referred to in the literature as "BCD" Curves) plotted in relation to source brightness and source size. The brightness is in footlamberts and the source size (Q) is in percentage of the field of view. The area below each curve is the area of comfortable response and the area above each curve is the area of uncomfortable response; the curve going through points that represent an equal division of response (*i.e.*, half of the observers reported the condition comfortable, and half, uncomfortable).

An examination of Fig. 1 shows that the real drawback of the data is that they cover only a part of the range of sizes (Q) of lighting systems, and from 1 to 100 footlambert adaptation levels, except for one observation by Petherbridge and Hopkinson at 1000 footlamberts. Moon and Spencer attempted extrapolation on the basis of their photochemical theory of vision. Where their base curve passes through the region of Holladays experimental data it does make a better fit (see Fig. 2) than any straight line that can be drawn through the points.

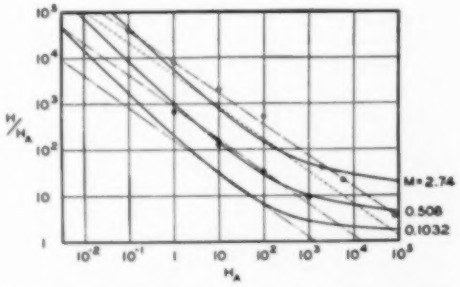

Figure 2. Allowable helios (brightness) ratio. • Experimental points of Holladay $Q = 5.5 \times 10\text{-}2$ steradian, sensation "just not unpleasant." (Figure 10. From "The Visual Effects of Non-Uniform Surrounds," Moon and Spencer, J.O.S.A., March 1945).

The Moon and Spencer Extrapolation

This extrapolation, when translated into BCD thresholds, plotted against source brightness and varying Q, appears as the dashed lines on Fig. 1. A check of the upward sweep of these curves, when prolonged into the region of star brightness and size (very small Q), shows them to be among the possibilities, since they obey Ricco's "Law." However, the downward slopes of these curves carried into the region of very large sources would lead to conclusions that are contrary to general observation. For example, it follows, as these curves level out, that for a given brightness of source the BCD response stays the same no matter how much the glare source is increased in size beyond about one per cent of the visual field. That is, that increasing the glare source in size beyond 1% of the visual field will not increase the glare.

The Holladay, Luckiesh and Guth, Harrison and Petherbridge and Hopkinson Data

The Holladay data (see Fig. 1) are plotted as straight lines. Straight lines, irrespective of slope or location, can only be approximately correct for a short distance. Extrapolated upwards into the small Q region they show BCD thresholds at a few thousand footlamberts whereas we know from universal experience with stars that the ultimate threshold in this region is up in the millions of footlamberts. Extrapolated downwards into the region of large Q they lead to predictions that do not check with experience. The Luckiesh-Guth data, as so far published, if extrapolated downward in the direction indicated would lead to the conclusion that a source of light over 10 per cent of the field in size will be uncomfortable just by virtue of size.[2] This is belied by our experience in natural fields of view where the maximum brightness is often a cloud or clouds occupying more than 10 per cent of the field, in a comfortable field of view.

The Harrison curves are displaced below the corresponding curves of the other investigators by an amount varying from 65 per cent to 88 per cent of the BCD values of the other investigators. Applying this observation to the probability curve in Fig. 8, it would appear that Harrison is using that visual condition that all people will find comfortable at all times, as his criterion. If Harrison's curves are adjusted on that assumption they will be found to be in reasonable agreement with the corresponding curves of the other investigators for sizes of Q running from 2/100th's of 1 per cent to 1 per cent of the field. They will also be found to be similarly unreliable for large or very small Q.

The Holladay curve, the Luckiesh and Guth curve, the Petherbridge and Hopkinson curve, and the adjusted Harrison curve, for the 10 footlambert threshold, agree closely between $Q = 0.05$ and $Q = 0.6$ (Fig. 1). The theoretical Moon-Spencer 10 footlambert curve passes through the other curves at the point where they also all agree, *viz.*, $Q = 0.4$, so this point seems reasonably well-established. The agreement in slope of four of the five curves also seems significant. However, the divergencies between the curves at the other levels prevents a satisfactory determination of the location of the other thresholds without additional data.

The 1000 Footlambert BCD Threshold

This additional data was sought in the records of natural lighting investigations made by one of the writers over a period of fifteen years. These records included measurements of the maximum brightness, its size and location and the mean brightness of the natural field in which each maximum brightness was measured. In each case the situation was judged as comfortable or uncomfortable by the available observers. From three to twelve observers were used in individual cases, but as these observers varied from scene to scene a total of about two hundred were involved in the entire series of observations.

These observations established the location of the 1000 footlambert threshold and its slope, from $Q = 0.1\%$ of field to 40 per cent, as shown in Fig. 3.

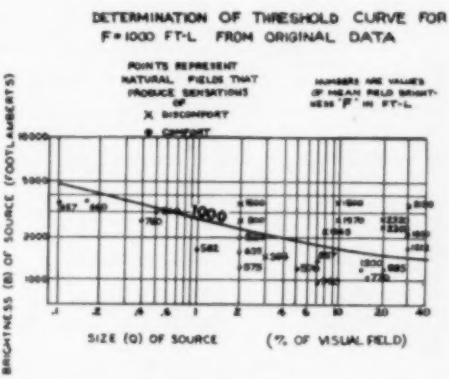
DETERMINATION OF THRESHOLD CURVE FOR
F=1000 FT-L FROM ORIGINAL DATA
POINTS REPRESENT NATURAL FIELDS THAT PRODUCE SENSATIONS OF
X DISCOMFORT
O COMFORT
NUMBERS ARE VALUES OF MEAN FIELD BRIGHTNESS "F" IN FT-L
1000
BRIGHTNESS (B) OF SOURCE (FOOTLAMBERTS)
SIZE (Q) OF SOURCE (% OF VISUAL FIELD)

Figure 3. Observations taken from fields of view in nature to establish the $F = 1000$ Ft-L threshold.

[2] A complete contradiction of the extrapolation of the Moon-Spencer method which would indicate that a size larger than 1% of the visual field is inoperative in increasing discomfort. However, later observations at $Q = 100\%$, communicated to the author and shown in Figs. 1 and 4, indicate the Luckiesh-Guth curves would bend back again in the region of large Q.

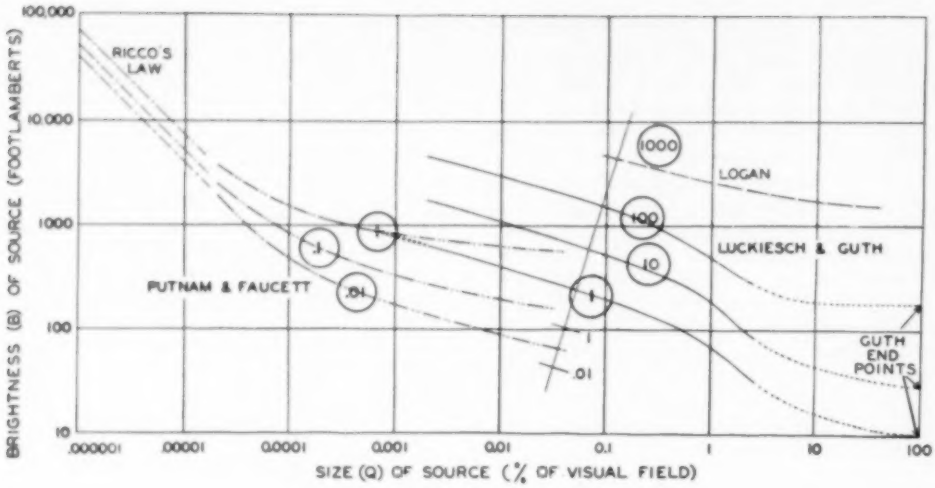

Figure 4. Basic Data for Visual Comfort Chart.

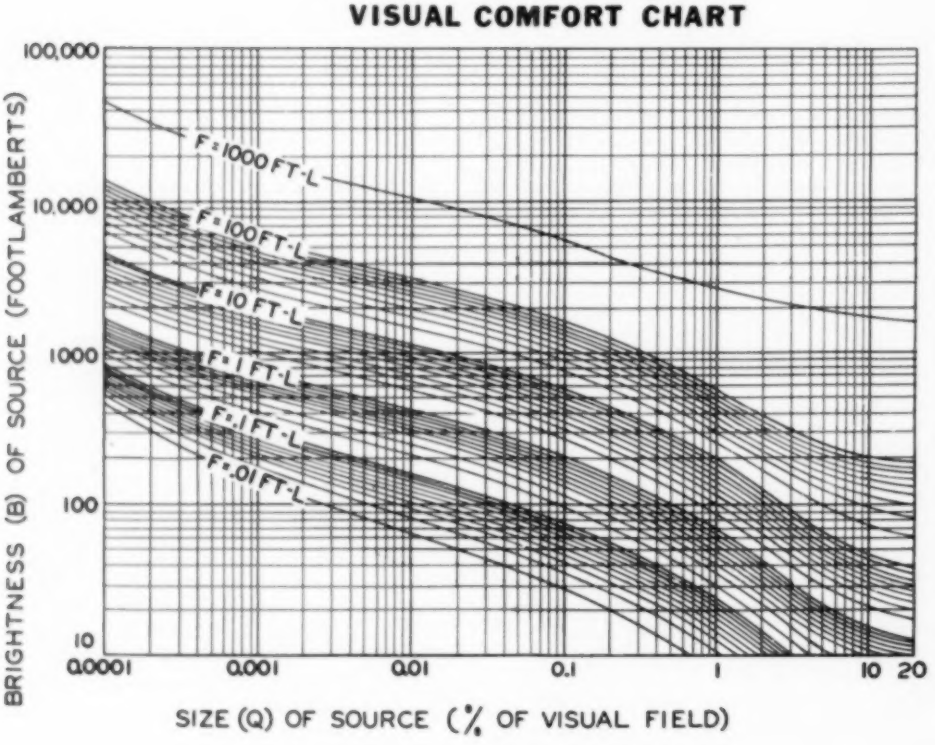

Figure 5. Visual Comfort Chart.

Location of the BCD Thresholds

As the various workers are in close agreement on the 10 footlambert threshold, and as the Luckiesh and Guth data are based on by far the largest number of observations, the Luckiesh-Guth curve was adopted for this level and carried out to meet the (communicated) end point observation of Guth at $Q = 100$ per cent. Also as a logarithmic relationship between the various thresholds was established by Holladay, and confirmed by succeeding investigators, even though they disagreed as to the precise logarithmic spacing; and as the evidence for the location of the 1, 10, 100 and the 1000 footlambert thresholds was strong, the logarithmic spacing adopted for the other thresholds was that dictated by these (see Figs. 1 and 4).

The Region of Very Small Q

Satisfactory continuation of the threshold curves into the region of very small Q is a problem, but the recently published work of Putnam and Faucett,[3] in which they worked with a source size down to $Q = 0.00002$ per cent, can be used as a tentative guide; particularly as their observations approached closely the region where Ricco's "law," requiring a slope of -1, takes effect.

These conclusions are put together in Fig. 4, which shows the basic data presently available for the construction of a visual comfort chart. With these data accepted the construction of a visual comfort chart showing BCD thresholds from 0.1 to 1000 footlamberts, and Q's from 0.0001 to 20 per cent of the visual field, becomes automatic.

Such a chart is given in Fig. 5.

Off-the-Line Brightnesses Versus On-the-Line Brightnesses

As the BCD threshold curves for the various adaptation levels shown in Fig. 5 are derived from data in which brightness on the line of sight was used as the reference state, while in everyday experience visual discomfort is usually associated with brightnesses off the line of sight, a method of translating off-the-line brightnesses into equivalent on-the-line brightnesses, is necessary.

Fortunately the work of Luckiesh and Guth on this phase of the problem provides an acceptable method of translation. If the position indices experimentally determined by Luckiesh and Guth[4]

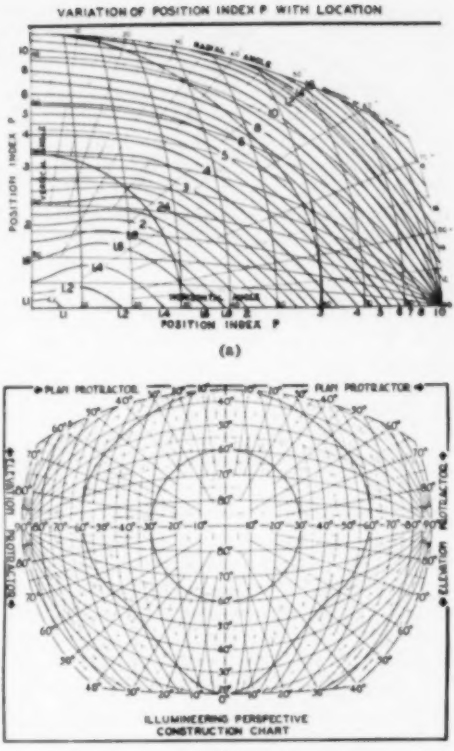

Figure 6. (a) The position indices determined by Luckiesh and Guth are laid out above on one "quadrant" of the spherical perspective protractor shown. This chart may be laid directly on a spherical perspective drawing, and the position indices of the various lighting units be ascertained directly in inspection. These indices are factors by which off-axis brightnesses may be divided to convert them to equivalent brightnesses on the line of sight. (b) Special protractor for spherical projection of the field of view.

are laid out on a spherical perspective construction chart as in Fig. 6, the position factor for any glare source or brightness in the field of view can be determined directly by inspection. As the position indices are symmetrical laterally it is necessary to show them on only one-quarter of the chart (left or right upper quarter). This position index grid can then be placed over the spherical perspective construction chart of any lighting job, permitting the position factor of any lighting unit, or brightness, to be read directly.[5]

[3] "The Threshold of Discomfort Glare at Low Adaptation Levels," R. C. Putnam and R. E. Faucett, Illum. Eng., Vol. XLVI, No. 10 (October 1951).

[4] "Brightness in Visual Field at Borderline Between Comfort and Discomfort," Luckiesh and Guth, Ill. Eng., Nov. 1949.

[5] This type of chart is described in "The Practical Mechanics of Designing Optimum Lighting Patterns," H. L. Logan, Ill. Eng., Dec. 1948.

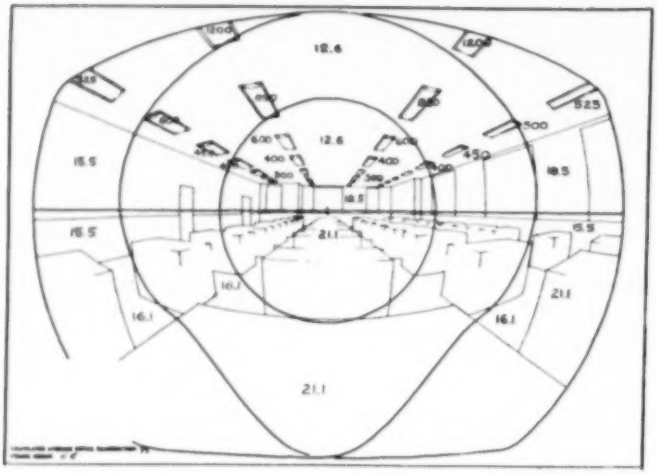

Figure 7. Spherical perspective of the installation analyzed in the text.

A typical computation is given in Table I. The first column, B, lists the actual brightnesses of the various lighting units in an actual job. The second column, Q, lists the actual area in square inches that the various lighting units occupy on the spherical perspective construction chart of the job. The third column translates the figures of the second column into percentages of the field of view, so it is also headed Q and simply states the size of the brightnesses in the same form in which they appear on the visual comfort chart.

The fourth column, P, gives the position index read directly from a position index grid (see Fig. 6) laid over a spherical perspective construction chart of the job (see Fig. 7).

The fifth column, B', is the result of the figures in the first column B divided by the figures in the fourth column P. They are therefore the "on-the-line" brightnesses that are the equivalent of the "off-the-line" brightnesses in the first column. It will be noticed that these equivalent "on-the-line" brightnesses vary from 37.5 to 300 footlamberts. As different brightnesses cannot be added it is necessary to convert them into one equivalent brightness.

This transposition becomes theoretically possible

TABLE I.—Comfort Evaluation Work Sheet AR 161.

B Ft-L actual source brightness from spherical persp.	Q Sq. in. from illumineering work sheet	Q % of field sq. in. $\times \frac{100}{250}$	P position index read directly	B' Ft-L $\frac{B}{P} = B'$ source converted to equivalent source on line of sight	Q' % when all $B' = 300$ from comfort chart transposition
1200	1.08	.432	12	100	.09
850	1.00	400	3.5	243	.63
600	.25	.100	2	300	.27
525	.74	.296	14	37.5	.0013
500	.55	220	5	100	.019
450	.21	.084	2.6	174	.057
400	24	.096	1.9	210	.11
300	20	.08	1.4	214	.1

TOTAL AREA Q' 1.28

INSTALLATION RATING IN % OF "BCD" BRIGHTNESS $\frac{200}{255} \times 100 = 78\%$

For adaptation level of 31.0 Ft-L.
This installation will be comfortable for 75% of Luckiesh and Guth's observers.

as a necessary and inevitable function of the fact that the BCD threshold curves, by definition, go through points of equal response. It also receives experimental support from the test of Luckiesh and Guth reported in ILLUMINATING ENGINEERING, Vol. 44, No. 11, page 663 (November 1949); the Petherbridge and Hopkinson demonstration of the validity of adding Q's of equal brightness reported on page 53, No. 2, 1950, *I.E.S. Trans.* (London), and the work of W. S. Stiles in 1929 (*Roy. Soc. Proc.*, 104B, p. 322). For example the following brightness and respective Q's, all lying on the 1 footlambert BCD threshold, are theoretically equivalent to each other: 1000 footlamberts—0.00037 per cent; 500 footlamberts—0.005 per cent; 200 footlamberts—0.11 per cent; 100 footlamberts—0.5 per cent. Therefore, the various "on-the-line" equivalent brightnesses can each be transposed into some other convenient brightness, such as 200 footlamberts, and the various equivalent Q's for this new brightness added together, so that the sum becomes the size of source which at that transposed brightness of 200 footlamberts is the glare equivalent on the line of sight of all the different, and differently located brightnesses in the field of view.

The present practical drawback to this theoretical situation is that the single experimental check that has been made produced the following results:

Guth's Room	Computed Per Cent Comfort	Judgment of 5 Guth Observers
"C"	77%	72%
"D"	71%	41%
"E"	50%	1%

The computation agrees reasonably with observers' judgment for most comfortable room, and agrees that rooms "D" and "E" are less comfortable in that order, but the observers are more severe in their judgment of the magnitude of the discomfort for these rooms. Also, although again theoretically, it should be possible to use any brightness within the group observed for the job in question, to serve as a base to which all the different brightnesses are equated, results may vary widely in magnitude (although not in direction). As the least error can occur when a brightness that is *intermediate* to the brightnesses of a given job is selected, the authors recommend the use of this value.

The fifth column of Table I gives the equivalent Q's for the job shown in Fig. 7. For example the top figure in this column is 0.09. This means that when the brightness of 100 footlamberts (top of adjacent column), having a Q of 0.432 (top of third column) is located on the visual comfort chart (Fig. 5) and the eye travels along the imaginary threshold line upon which this point falls, which is parallel to the adaptation threshold line of the job, until it intersects the horizontal 200 footlambert line, it will be found to intersect this line where it crosses the vertical Q line of 0.09. In other words, a 100 footlambert brightness occupying 0.432% of the visual field on the line of sight, is the equivalent of a 200 footlambert brightness occupying 0.09% of the visual field in the same position. All the Q's shown in the sixth column of Table I are the equivalent Q's when the brightnesses adjacent to them are transposed to 200 footlamberts.

These equivalent Q's add up to 1.28% of the visual field. Therefore, the different brightnesses in the first column of Table I, with their varying sizes in the third column, and their varying positions in the visual field as indicated by the position indices in the fourth column, can be equated to one glare source on the line of sight, having a brightness of 200 footlamberts and occupying 1.28% of the visual field.

As the adaptation level for the job in question was 31 footlamberts, and as it can be found by inspection of the visual comfort chart that the BCD threshold for a Q of 1.28% of the visual field is 255 footlamberts at that adaptation level, then the glare situation on this job is 78% of the BCD threshold for the job, $\frac{(200)}{(255)}$.

This means, on the basis of a plot of the scatter of observer's responses given in Fig. 8, that 75% of observers would give a comfort response. It also means that present available data, used in this way, make it possible for the illuminating engineer to predict the probability that x observers will find

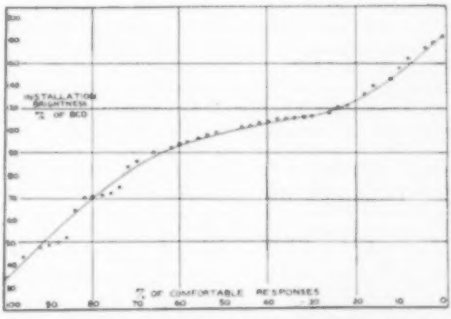

Figure 8. Plot of the Scatter of Observer's Comfort-Discomfort Responses. Data from Luckiesh and Guth, Brightness in Visual Field, ILLUMINATING ENGINEERING, November 1949, page 653, Table I, 50 Observers.

a given situation visually comfortable and when the analysis shows an undesirable situation, it will also indicate where the trouble is, and by implication, what can be done about it.

Appendix A — Random Versus Critical Seeing

Mr. S. K. Guth, in his paper "Comfortable Brightness Relationships for Seeing," Illuminating Engineering, February 1951, presents evidence indicating that observers engaged in critical seeing are tolerant of twice as much glare stimulus from lighting units, as those engaged in random seeing.

This leads Ward Harrison to comment in the discussion of this paper that "Evaluations according to Logan's flux analysis method and the writer's glare factor system presuppose that the observer is not engaged in critical seeing but is simply looking forward in a substantially horizontal direction. Apparently, these premises are the correct ones."

In short, the method of evaluation described in this paper would therefore ensure that a pre-determined degree of visual comfort would obtain under all conditions in a given environment, as it is based on the most severe requirement, namely, that of random vision.

Further, if Mr. Guth's evidence is sufficient, the comfort relations for critical seeing can be found by dividing the percentage of BCD summation for random seeing by 2. If that is applied to the case used in this paper the summated figure becomes 39% of BCD, instead of 78%, and the number of people who would give a comfortable response would rise from 75% to 97%.

Appendix B — Adaptation Level

Most investigators have treated the source brightness, the surround brightness and the adaptation brightness[6] as three physically disassociated quantities. This is, perhaps, logical under laboratory conditions, yet they are not independent in real life. This may not be important, but it seemed important to the writers because in practice the light source not only sends light to the eye, but also to the field and thence to the eye. For any one field of view the light to the eye is 100%, and the light directly from the source to the eye is 100% less the light from the surround.

The eye adapts to this combination, or total effect, in actual working conditions where the light source is either a large area, such as an indirectly lighted ceiling, luminous ceiling or louverall ceiling, or is a multiplicity of smaller areas varying from indirect coffers to bare lamps.

The observer is met with two situations in considering the adaptation level, although the literature emphasizes only one of them. The first, generally overlooked, but probably the commonest, is that in which people scan the field, where they meet a succession of different brightnesses with extremely short fixation pauses, averaging 15/100ths second. This is not long enough to permit the eyes to adapt to any one fixation point.

It would seem that, in this case, the eyes have no choice but to adapt to some intermediate value which they maintain with minor variation as long as they remain in the particular field of view.

The second situation, and the one with which the literature is concerned, is where the eyes are scanning a restricted part of the field (the work) and the background of the work is constant in brightness. The eye is therefore dominated by this small part of the field, and is assumed to adapt to it.

There seems no doubt that the adaptation of the fovea for purposes of visual acuity is so dominated, and this foveal adaptation is related to disability glare; but no data have yet been uncovered that relate disability glare to discomfort glare. The two effects are different and there is more than a suspicion that they use different structural features of the body for their expression. Further, there is some evidence to show that in some circumstances discomfort glare can improve visual acuity, whereas disability glare can only reduce it.

The assumption that the adaptation of the eye for comfortable operation is the same as its adaptation for keen vision remains in the realm of speculation.

One thing is clear: the eyes adapt to a value that is intermediate to the actual brightnesses encountered, in any event.

What is this intermediate value? Moon and Spencer propose the following formulae:

$$H_A = \frac{K}{\pi} \int_{\phi_1}^{\phi_2} d\varphi \int_{\sigma_1}^{\sigma_2} H(\sigma\varphi) \cdot \sigma^{-2} \sin\sigma \cos\sigma \, d\sigma$$

This requires impractical precision in the data and is too complicated and time consuming for field use. Engineers need a simpler tool that handles the orders of magnitude in which field data are available.

The brightness of the work, or, as in some glare experiments, the brightness of the surround, minus the light sources, has been taken as the adaptation brightness up till now.

It is hard to imagine, in real life, a situation in which the brightness of the surround, independently of the light sources in the field, can adapt the eyes from the standpoint of comfort response: although if one accepts the Moon-Spencer concept of adaptation brightness one may ignore, in most cases, the glare flux to the eyes in establishing the adaptation level. That is, one may use the light to the eyes, of whatever part of the field one is looking at, as the adaptation level. This is due to the Moon-Spencer formula being weighted so heavily in favor of the foveal region that the effect of the rest of the field comes out at fractions of a per cent, and is therefore negligible.

There is basis for this when dealing with visual acuity, but its connection with visual comfort has not been demonstrated.

The brightness of the work is a satisfactory approximate criterion where it is constant and conditions are such that it is clearly the dominant factor in adaptation. The effect of this is to establish a slightly lower level of adaptation than the fact, and so a more severe discomfort threshold for job in question. This is a safety factor that has a beneficial aspect in practice.

There are, however, many situations where it is difficult to pin the work to a surface with which the eyes are steadily engaged. Restaurants, courtrooms, lecture rooms, legislative halls, conference rooms, and many offices, institutional and educational interiors are cases in point.

In looking around for a simple answer to this problem of adopting a workable equivalent of the true adaptation level it was found that the mean brightness of the field of view was usually close to the work brightness, where the work brightness was the dominant factor, in 41 cases checked. These included classrooms, offices, banking rooms, central station control rooms and many types of work interiors.

[6] When the adaptation brightness is the work brightness.

It therefore appears that, as in situations where the work brightness is a satisfactory approximation of the adaptation level, the mean brightness of the field runs the same on the average, the balance of probability is in favor of the mean field brightness value being a good working approximation of the adaptation level, and the writers are so using it in making practical applications of the visual comfort evaluation method discussed in this paper.

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DISCUSSION

SYLVESTER K. GUTH and PHELPS MEAKER*: The authors have made a very interesting analysis of some of the available visual comfort data and have developed a unique method for evaluating the visual comfort of lighting systems. Only by such efforts can we hope to explore the various possibilities for practicalizing basic data and arrive at a simple and workable procedure that will be accepted and used by the illuminating engineer. The ultimate solution probably will be a composite of the methods suggested by several individuals.

The comparison of the empirical formulae developed from the results obtained by various investigators is interesting. However, when such a comparison is made it is necessary to keep in mind the differences in the techniques, experimental conditions, range of variables, observers, etc., as used by each of the investigators. Over-simplication of the relationships among the factors of source size and brightness and the adaptation brightness simply invite unwarranted generalization and extrapolation. The ranges of sizes of sources used by the three investigators who did original work are compared in the following table:

	Range of Size of Sources	
	Steradians	Per Cent of Visual Field
Holladay	0.00004 - 0.009	0.0008 - 0.18
Guth	0.0001 - 0.13	0.002 - 2.6
Petherbridge and Hopkinson	0.00027 - 0.027	0.0054 - 0.54

The Holladay formula quoted represents his complete data very well. The Guth formula represents only the straight line portion of his data up to a size of about 0.01 steradian; the expression that represents the relationships among the factors over his entire range is

$$\text{Glare Constant } (M) = \frac{B}{PF^{.44}\,(Q^{-.21} - 1.28)}$$

If, for convenience in comparison, this formula is converted so that the adaptation brightness F is to the first power, it would appear to be considerably more complex. Petherbridge and Hopkinson themselves state that their equation holds only "over a very limited range." The Harrison formula was based upon the data available at the time of its conception (largely Holladay's) plus a considerable amount of analysis and judgment. The Moon and Spencer equation is another attempt to fit the Holladay data, which apply only to 0.009 steradian, to a relationship extending to about 0.5 steradian; it involves considerable unjustifiable extrapolation.

The number and type of observers used in the various investigations also is important, especially when comparing the absolute values of BCD brightness. To make such a comparison it is necessary to know how representative or "average" they are as individuals and as a group. Luckiesh and Guth were fortunate in being able to select a group of 10 observers who were representative of a larger group of fifty. The results obtained with the latter indicated a good approximation to a normal distribution. In general, the agreement among the results obtained by the three investigators is very good when one considers the differences in experimental procedures and observers and in the criteria used by each.

The authors mention the drawbacks of the limited ranges of sizes and adaptation levels covered by the available data. The former were limited in part by experimental facilities. However, the more recent determinations as presented in their Fig. 4 illustrate the probable effect of larger sources. The upper value of 100 footlamberts for the adaptation brightness does not seem to be particularly limiting. This corresponds to about 125 footcandles on white paper and even higher levels on lower reflectance surfaces. A slight extrapolation to adaptation brightnesses of 150 or 200 footlamberts should not result in large errors.

The authors use their Visual Comfort Chart for two purposes. The first is to transform one source of a specific size and brightness into another source of a different size and brightness which will produce the same visual sensation. This seems to be a valid procedure. It should be emphasized strongly that while the curves of the Visual Comfort Chart appear to be similar to the Luckiesh-Guth curves of Fig. 4, the authors have adjusted the latter to conform to their judgment of a representative series of curves.

*General Electric Company, Nela Park, Cleveland, Ohio.

After summing up the new values of Q', they again use the Visual Comfort Chart to determine the permissible brightness of the total area Q' of the sources which now are considered to be combined and located on the line of vision. The significance of this sum is questioned because each value of Q' actually pertains to a different sensation if a constant adaptation brightness is assumed. Conversely, if equal sensations are assumed, then different adaptation brightnesses are involved. The individual values of Q' used by the authors represent distinct visual situations, the characteristics of which can be determined from the Visual Comfort Chart. For example, if Q' equals 0.65 per cent and B equals 200 footlamberts, the corresponding adaptation brightness from the Visual Comfort Chart is about 6 footlamberts for the BCD sensation. When Q' is 0.012 per cent (B = 200 footlamberts as before) the adaptation brightness is 0.2 footlambert for the same sensation. If equal adaptation brightnesses are assumed, it should be obvious that different visual sensations are involved. Thus, it seems difficult to reconcile the sum of dissimilar quantities such as these, which bears no known relationship to the BCD data, with a meaningful number that can be used to appraise a lighting system.

The references the authors cite to support their method of addition to determine the total sensation do not seem to be applicable to their conditions. The Luckiesh-Guth test involved pairs of symmetrically located sources — a very special condition — and applies only to the combining of certain pairs of sources of equal brightness and area in the first step. However, the final summation of the values of Q' (column 6 of Table I) is unsupported by research or experience. Petherbridge and Hopkinson conclude from their experimental results: "This indicated that arithmetic additivity, such as was found in the street lighting work, did not apply to these larger sources of lower brightness." Furthermore, in the special case where they found that there was a simple additivity effect, it was applied to summing the surround brightnesses (which was their experimental variable) required for the BCD sensation with each glare source. In other words, they were adding for an entirely different set of conditions. The work of Stiles is not pertinent since his results are in terms of the brightness difference threshold which cannot be related to sensations of comfort and discomfort.

The Guth method may be applied to the example illustrated in Fig. 7. Using the values of B, Q, and P presented in Table I for those units which lie within approximately a 50-degree zone, the resulting index of sensation M is 110. This indicates that the installation would be expected to be comfortable for about 50 per cent of the observers if they were all located at the end of the room. This is a considerably smaller number than that determined by Logan and Lange.

The data that are currently available provide information for determining the probable sensation of visual comfort that would be induced by a single source or by two symmetrically positioned sources standing alone in the visual field. No positive clue is offered for the determination of how much each source contributes to the total sensation induced by a group of sources. To provide such information would require an investigation of every possible arrangement of lighting equipments that is used in practice. Therefore, at present, any method of combining sources must be on an empirical basis. It is pointed out that the Guth method was developed from experimental data with circular sources,[1] checked with linear sources[2] and with actual lighting equipments.[3] It is believed that any method should be relatable to the available data and should be checked experimentally.

References

1. Brightnesses in Visual Field at Borderline Between Comfort and Discomfort (BCD), Matthew Luckiesh and S. K. Guth, ILLUMINATING ENGINEERING, Vol. XLIV, p. 650 (1949).

2. Comfortable Brightness Relationships for Critical and Casual Seeing, Sylvester K. Guth, ILLUMINATING ENGINEERING, Vol. XLVI, p. 65 (1951).

3. BCD Brightness Ratings in Lighting Practice, Sylvester K. Guth, this issue, ILLUMINATING ENGINEERING, p. 184.

WILLARD ALLPHIN*: Mr. Logan has produced another of his scholarly and thought provoking studies on what constitutes good lighting.

The authors of each system are better able than I to criticize the way in which the systems have been fitted together but it seems to me that the effort has been worth while and rewarding. If there are discrepancies, they are probably no greater than those existing between one subject and another.

Mr. Logan's paper throws further doubt upon the value of brightness ratios such as 3:1 or 5:1 as used to cover a wide range of situations and footlambert levels. Actually does it not indicate that there are a multitude of comfortable brightness ratio limits, depending upon the circumstances in each case?

H. L. LOGAN and A. W. LANGE**: The discussion of Messrs. Guth and Meaker develops several points that can benefit from further clarification. First, it seems a little confusing to discuss "the ranges of sizes of sources used by the three investigators who did the original work" without referring at the same time to the work of Putnam and Faucett who extended the data down of 0.00002 per cent of the field of view; and the work of Mr. Guth in establishing the end points of the 1, 10 and 100 footlambert thresholds at 100 per cent of the field of view that he communicated to the authors. That is, instead of data being available only from 0.008 per cent of the field of view to 2.6 per cent, as a casual reader of Messrs. Guth and Meaker's discussion might conclude, data are available from 0.00002 per cent to 100 per cent of the field of view.

When we consider that "Ricco's Law," based upon experimental evidence, carries us down to star size, data are actually available on source size from the nearly infinitely small to the full size of visual field. However, there is a gap in the data between 0.00002 per cent of the field of field of view and the region of still smaller source sizes to which Ricco's law applies. There is also a conflict between the Luckiesh-Guth data and the Putnam-Faucett data in the region running from 0.001 to 0.05 per cent of the field of view. Finally, there is a gap in the Luckiesh-Guth data between 2.6 per cent of the field of view and the end-point observations at 100 per cent. All of this is clearly shown in Figure 4 of our paper.

Second, the curves of the Visual Comfort Chart shown in Figure 5 not only "appear to be similar to the Luckiesh-Guth curves of Figure 4," but they go through the experimental points reported by Messrs. Luckiesh and Guth as accurately as we could draw them. The "adjustment" of the curves that Messrs. Guth and Meaker mention must

*Sylvania Electric Products Inc., Ipswich, Mass.
**Authors.

refer to an earlier set of curves that were "adjusted," but that set was abandoned as a result of discussion with interested authorities, and the exact Luckiesh-Guth curves were adopted without adjustment for the region for which experimental points were given.

Third, we feel that Messrs. Guth and Meaker have missed the essential point of the paper in their attempt to dissect Q' values into separate, distinct visual situations. It is true that the experimental values were established separately, as that is the only way in which the variables could be controlled to give reproducible results; but the conscious or unconscious postulate was that they could be used in combination (in fact Mr. Guth attempts to so use them), otherwise the experiments were futile. Guth and Meaker claim that individual sources and their co-ordinates represent distinct visual sensations, and thus cannot be combined in the manner we suggest. However, individual sources are parts of an entire visual environment to which the eye is adapted. They do not operate to produce individual, disparate sensations but simply contribute to the summation that produces adaptation. Messrs. Guth and Meaker agree that individual sources can be equated, via the Visual Comfort Chart, into other sources of different brightnesses and sizes, but stop short at the next step without which the entire process is useless to the engineer.

BCD thresholds are by definition thresholds of equal response. If the experiments are reliable, and we accept them as such, any two co-ordinates on a BCD curve represent a situation to which the response is the same as that represented by any other pair of co-ordinates on that curve. If, therefore, all the different source brightnesses are equated to one brightness by this method of transposition we have a variety of sizes of source, each of which has the same brightness. We believe they can be added because they are elements of the total sensation from the field that have been reduced to only one variable — size. Putting it differently, Messrs. Guth and Meaker believe we are correct in transforming one pair of co-ordinates into another, but do not agree that we can take the next step, which is to transform a number of pairs of co-ordinates into one pair which sums up the entire glare situation for a given field of view.

We believe that if the first step is possible the next step is a rigorous necessity. As a practical matter it may not work if the curves are not correct; that is, if the experimental data, or its interpretation is faulty. We have taken the data that are available. We would like better data, and time will undoubtedly furnish it. Meanwhile, as a result of practical experience with our method of summation we are satisfied that it produces results of an order worth using. We can, by this method, duplicate the order of judgment of Mr. Guth's five observers, and where the field of view verges on the comfortable we can come close to the magnitude of their judgment. For example, as shown in the paper, where they give a 72 per cent comfort judgment we compute a 77 per cent comfort response. We part company in magnitude of prediction where the degree of discomfort becomes considerable, but even there the figure we compute would result in rejection of the proposed lighting installation so that its practical effect is the same.

Readers will recall that Mr. Guth mentioned these observers in his paper "BCD Brightness Ratings in Practice," and we referred to the computed check we made against their judgments in one experimental case, in our paper. It seems doubtful to us that these five trained observers represent the lay reaction of the general public to visual discomfort. We would expect them to be, as we find them, somewhat on the severe side. We do not therefore think that our failure to exactly match their judgments by computation in one case is a sufficient argument against a summation method that is so theoretically sound.

Jewelry Displayed By High Level Lighting

General illumination in the King's Jewelry, Duquesne, Pa. is provided by nine ceiling mounted four-lamp 40-watt fluorescent luminaires with diffusing glass sides and louvered bottoms. Merchandise in full view in glass counters or under inspection on top is highlighted by a system of 24 recessed PAR-38 reflector units, on two-foot centers. Average general illumination is 95 footcandles, and on counter tops is 180 footcandles. ***Photo courtesy Duquesne Light Co., Pittsburgh, Pa.***

Exterior Lighting for a Factory Office Building

LIGHTING OBJECTIVE: To identify a manufacturer's branch office building at night, emphasizing the striking modern architectural features.

Installation at W. P. Fuller Paint Company, 222 North Avenue 23, Los Angeles, California.

General Information: This modern building houses the district offices of a paint, glass and wallpaper manufacturer and is located adjacent to the factory and warehouse.

The tower sidewall on which the large sign is mounted is "light madrone tint" (beige, 59% RF) and the sign letters are dark green. (Sign over doorway is dark green also.) Tower bars between floors are ice blue, blending in with the glass block. The general trim is "medium madrone tint" (warm grayed brown, 28% RF), with a "green acid stain" sidewalk entrance.

The tower wall (approximately 60 feet tall) is built of Pittsburgh-Corning Essex B55LX glass block specially constructed with fiberglass mat filters midway between each parallel surface of the block for purposes of heat insulation and to decrease inside glare from direct sunlight.

The all-glass foyer consists of Herculite $\frac{3}{4}$-inch plate glass doors and Solex plate glass show windows. Mississippi Structural Corrugated Glass panels above the doorway are covered by draperies on the interior.

Installation: The glass-block wall is illuminated by a continuous row of industrial type fluorescent luminaires mounted vertically at either side of the tower. Each luminaire contains two 96-inch T-8 lamps operated on 200-milliampere ballasts.

The sign and pylon are floodlighted by four 500-watt Smoot-Holman No. 1605 ST units located on the roof below, 24 feet back from the face of the pylon and spaced 4 feet apart. These floodlights are turned on at 6 p.m. and off at 11 p.m. each night automatically by a time clock. On clear nights the tower sign is visible 3 to 4 miles.

The back-lighted sign W. P. Fuller & Co. is illuminated by two rows of tangerine-colored 20 mm cold cathode tubing operated at 300 milliamperes on a 15,000-volt transformer; the rows are spaced 6 inches apart. Reflected light shown above sign is from the white canopy.

This building was designed by Architect Adrian Wilson and Associate Alden Becker.

Lighting data submitted by Illuminating Engineering Unit, Department of Water and Power, City of Los Angeles as an illustration of good lighting practice and to aid in the design of similar installations.

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Color Correction and Other Important Improvements In Mercury Lamps

By H. D. FRASER
W. S. TILL

New design features have greatly improved mercury vapor lamps. A new method of introducing lead wires into quartz arc tubes is described as well as the use of a larger size arc tube, a new type of outer bulb and a new basing cement. These improvements have resulted in longer life, better maintenance and greater dependability for mercury lamps. Of outstanding interest is the development of a new high temperature phosphor for color correction of quartz mercury vapor lamps. Data are given which include the absorption and luminescence spectra for the phosphor and the spectral energy distribution and technical characteristics of a phosphor coated lamp.

THE HISTORY of the electric lamp has been one of steady improvement in the efficiency of the production of light. Many new types of lamps have been invented, and the development has generally been in clearly defined stages, each stage bringing forth a new lamp. However, the present era of development has produced not one but several new types, of which the fluorescent and quartz mercury vapor lamps are outstanding.[1] This paper will describe some of the newer developments in the quartz mercury vapor lamp which have made it a light source of higher efficiency, longer life and superior performance. Fig. 1 shows the significant improvement in the average life rating of typical lamps during the last few years, and Table I lists technical characteristics for several types.

New Method of Introducing Lead Wires into Quartz Arc Tubes

Since the very first use of quartz arc tubes for mercury vapor lamps, the method of introducing the current carrying lead wires through the silica wall has presented one of the most difficult problems in their manufacture. The differences in coefficients of expansion between quartz and metals (approximately 1 to 8 for tungsten, which is commonly used) and the extremely high fusing temperature of quartz, in the neighborhood of 1750°C, have prohibited the direct sealing together of these materials. Consequently most quartz mercury vapor lamps used a graded seal of one type or another. The graded seal consisted of a series of glasses of graduated expansion and temperature characteristics which bridged the gap between the quartz and the metal lead wire.

Even though carefully controlled methods were used in their manufacture, graded seals often developed cracks at unpredictable stages of their life. In recent years, a more practical and dependable seal has been developed for quartz mercury vapor lamps. It consists of a thin molybdenum metal ribbon pressed between two walls of quartz or other similar material. The ribbon is so thin that the forces exerted by expansion and contraction are negligible and a vacuum tight seal is effected. Until now, however, this seal has been regarded as impractical for large scale production and was used only for some special types of lamps. Recently, a new technique in the manufacture of this ribbon seal has been developed which lends itself to high production methods and enables the new seal to be used for many lamp types. Fig. 2 illustrates the new ribbon seal.

Use of Larger Size Arc Tubes and Outer Bulbs

Many different formulas have been put forward by designers of mercury vapor arcs to determine the conditions necessary to produce the best overall balance between high efficiency, long life and good maintenance. Results of a large number of tests have indicated that arc tube loading (watts per square centimeter of arc tube area between the electrodes) is the most important factor in determining these characteristics. Recent investigations have shown that this figure should not greatly exceed 10 watts per square centimeter in order to obtain the best performance.[2] The former arc tube sizes have given loading values up to 14. Various design changes were tried to reduce this value to 10 or below and the one found to be most effective was an increase in arc tube diameter. Consequently, arc tube diameters were increased

A paper presented at the National Technical Conference of the Illuminating Engineering Society, August 27-30, 1951, Washington, D. C. Authors: Westinghouse Electric Corp., Lamp Div., Bloomfield, N. J.

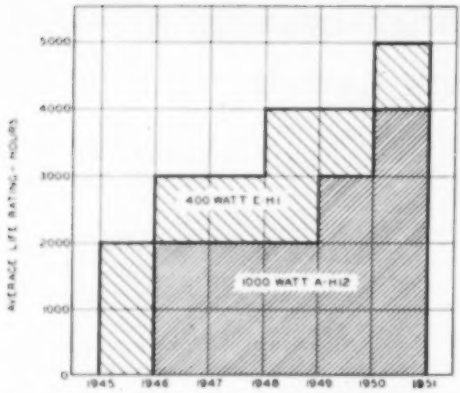

Figure 1. Average life performance of typical mercury vapor lamps with quartz arc tubes has improved 100% or more during recent years.

and life and efficiency records have more than justified this change in design.

Another notable improvement in recent quartz mercury vapor lamps is the use of considerably larger outer bulbs. This change in size not only increases the life and efficiency of the inner arc tube but permits use of a low temperature glass for the outer bulb, as will be shown later. It is well known that the temperature and composition of the glass of the outer jacket influence the life and performance of the quartz arc tube. This is chiefly due to the fact that water vapor evolves slowly from the glass outer jacket during operation of the lamp, and in turn this vapor breaks down under the conditions of high heat and strong ultraviolet light into hydrogen and oxygen. The oxygen is absorbed by the metal parts and the hydrogen diffuses through the quartz wall of the arc tube eventually making the lamp inoperable.[3]

Since the rate at which water vapor is evolved depends directly on the temperature of the outer jacket, and since a larger outer bulb will be cooler, its performance will be better. In addition, the temperature of the outer jacket is kept as uniform as possible over its entire surface by means of a special bulb shape. This prevents local overheating of the glass wall. When the lamps are burned horizontally in enclosed fixtures, as in street lighting where bulb temperatures run higher than usual, the benefits from the larger cooler envelope are particularly important.

Another condition which also affects the evolving of water vapor is the type of glass of which the outer bulb is made. Different types of glass were found to vary greatly in the rate at which water vapor was evolved. Some types of lime glass bulbs were found to be especially satisfactory in this respect.

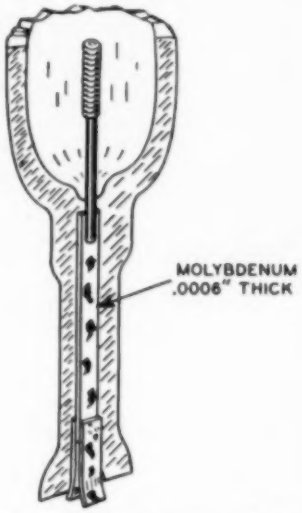

Figure 2. Thin metal ribbon, vacuum sealed into quartz, eliminates strain and provides dependable means of introducing lead wires into quartz arc tubes.

Another advantage derived from the use of the larger lime glass outer bulb in a 400-watt quartz mercury lamp is that the base temperature has been found to be approximately 25°C cooler in most fixtures when the lamp is operated "base up." In addition, the use of the lime glass outer bulb makes for better quality control because this glass is used in the manufacture of the great majority of incandescent lamps and thus there is available the vast amount of knowledge and experience gained with it over the years in this industry.

Consequently, the combination of a larger arc tube with a larger outer bulb of "isothermal" shape,

TABLE I—Characteristics of Typical Quartz Mercury Vapor Lamps for General Lighting.

Type	A-H4	C-H5	E-H1	A-H12
Nominal Lamp Watts	100	250	400	1000
Approx. Initial Lumens	3300	11,000	20,000	55,000
Rated Average Laboratory Life At 5 or more burning hours per start	1000	4000	5000	4000
Max. Overall Length (Inches)	5¼	8	11¼	14
Approx. Light Center Length (Inches)	3½	5	7	9
Approx. Outer Bulb Diameter (Inches)	1¼	1¾	4½	3½
Outer Bulb Glass	#1720	#1720	#0080	#1720
Base	Admed. Sc.	Mog. Sc.	Mog. Sc.	Mog. Sc. Mech.
Burning Position	Any	Any	Any	Any

Consequently, the combination of a larger arc tube with a larger outer bulb of "isothermal" shape,

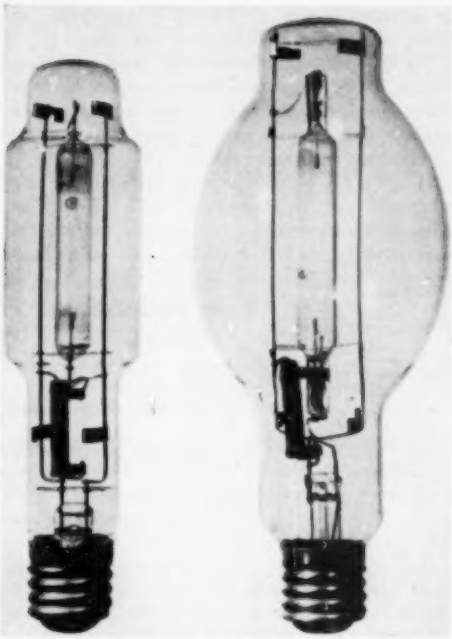

Figure 3. New larger "isothermal" bulb and larger arc tube, with ribbon seal, have greatly improved performance of quartz mercury lamps. The old and new 400-watt type E-H1 lamps are illustrated.

made of lime glass, appeared to be a logical step to better lamp performance. A lamp with these features has been recently made available and is illustrated in Fig. 3.

New Basing Cement

Another development is the use of the new silicone cements in basing. Hitherto most methods of basing high temperature lamps required indented molding of the glass neck in order to provide a means of locking the base to the bulb. These indentations have been a potential source of glass strain frequently leading to lamp failure. With the use of silicone cements, the indentations are no longer necessary. These new cements will retain their adhesive properties over extremely long periods of time at temperatures approaching 300°C, which are well above the range of base temperatures normally encountered in mercury lamp fixtures.

Color Corrected Lamps

A New High Temperature Phosphor. — Mercury vapor lamps have many fine qualities—particularly long life, high efficiency and high output. They produce a distinctive color of light which is widely accepted in industrial lighting and frequently advantageous as in floodlighting, or lighting a street, etc. For many applications, however, color discrimination is involved and mercury lamps are not acceptable unless incandescent lamps are also used in the installation. The incandescent lamps have a wealth of red energy which is almost completely lacking in mercury lamps and which improves the color of the light provided by the system. However, since the efficiency of filament lamps is only one-third to one-half that of mercury lamps and the life is only one-quarter as long, it has long been desired to have a mercury lamp of better color characteristics which, at the same time, would retain the other advantages of mercury lamps.

Previous attempts to add color to these lamps by the addition of cadmium and zinc, which have excellent lines in the red spectral region, have proven impractical for standard lamps. These metals are less efficient light producers than mercury and vaporize less readily. All other metals examined so far have proven equally impractical. Therefore, research has turned toward utilizing phosphor powders rather than metallic vapors for color correction. One of the advantages of a phosphor is that it need not substantially lower the efficiency of the mercury lamp. This is because the phosphor can be chosen to respond to the invisible ultraviolet energy which is ordinarily wasted, and because there is actually more ultraviolet energy in a 400-watt quartz mercury arc than there is visible energy.[4]

To be of practical advantage in the color correction of mercury lamps, a phosphor should possess the following characteristics:

1. It should be as white as possible so as not to subtract materially from the visible mercury emission.
2. It should respond efficiently to all wave lengths of the ultraviolet available from the arc.
3. It should possess this same kind of response at temperatures in the order of 300°-500°C.
4. It should luminesce in the spectral ranges where mercury is deficient — that is, primarily the red.
5. It should be thermally and photochemically stable at the temperatures and radiation densities encountered in quartz mercury vapor lamps.

A phosphor has been developed which fulfills these requirements well. This is the magnesium fluorogermanate described by Thorington in a recent paper.[5] By reference to Fig. 4, it will be seen that the phosphor is excited by energy principally throughout the ultraviolet and partly in the visible spectrum.

The spectral distribution of the luminescence of magnesium fluorogermanate is shown in Fig. 5. Virtually the entire output of the phosphor is in

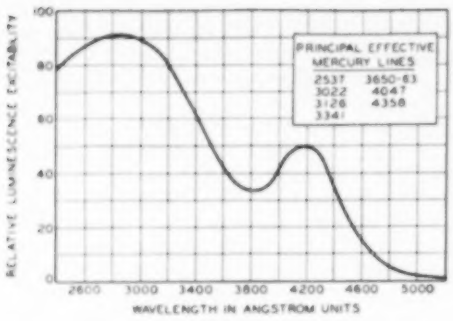

Figure 4. Magnesium fluorogermanate phosphor absorbs ultraviolet energy, particularly in the shorter wave lengths.

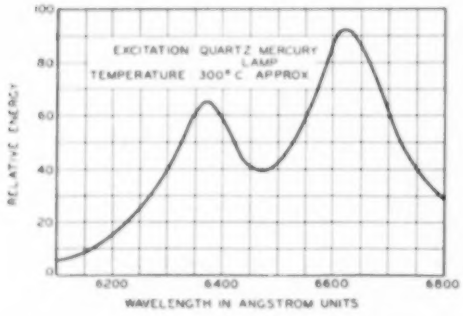

Figure 5. The phosphor luminesces in the red spectral region where mercury lamps are noticeably deficient.

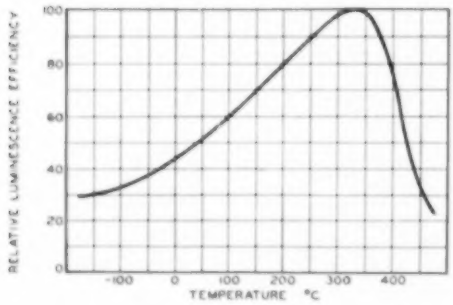

Figure 6. Magnesium fluorogermanate phosphor is most efficient at the high temperatures reached by the outer bulb of a mercury lamp.

the spectral region of 6000-7000 Angstroms, in which region mercury lamps are deficient.

Fig. 6 shows the temperature dependence of magnesium fluorogermanate. This phosphor is most efficient at temperatures of 300°-350°C, which makes it the first practical phosphor for high temperature mercury vapor lamps.

Thus, it has been clearly shown that the new magnesium fluorogermanate phosphor (1) utilizes ultraviolet energy which is normally wasted, (2) luminesces in the red spectral region where mercury lamps are deficient, and (3) operates best at the high temperatures reached by the outer bulb of mercury vapor lamps.

The J-H1 Color Corrected Fluorescent Mercury Vapor Lamp

During 1950, a 400-watt color corrected mercury lamp employing magnesium fluorogermanate phosphor made its appearance and was designated type J-H1. In this lamp, the phosphor coating is applied to the inside of an outer bulb specially designed to provide the desired temperature uniformly over its surface. Fig. 7 shows a sectional view of this lamp. In addition to the isothermal bulb, the J-H1 contains other important improvements as previously mentioned.

Fig. 8 shows the spectral energy distribution of the J-H1. If the energy radiated by this lamp between 6000-7000 Angstroms is converted into lumens, it amounts to 10 per cent to 12 per cent of the total visible radiation from the lamp. This is

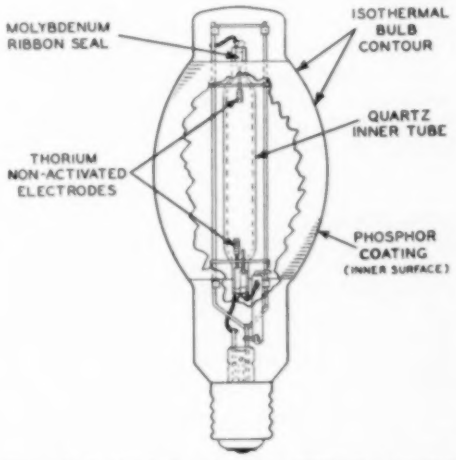

Figure 7. Sectional view of the type J-H1 color corrected mercury lamp employing the new magnesium fluorogermanate phosphor.

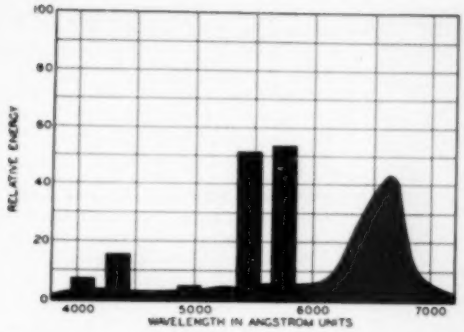

Figure 8. Spectral energy distribution of the 400-watt J-H1 color corrected mercury vapor lamp.

approximately the same percentage of red energy as is present in daylight.[5] While the J-H1 does not duplicate daylight, it does provide "white" light suitable for most industrial needs.

The J-H1 lamp has an initial efficiency of 45 lumens per watt and is rated at 4000 hours average life at the present time. Electrically, it is the same as the 400-watt E-H1 quartz mercury vapor lamp and, like it, will also start reliably at temperatures down to 30°F below zero, when the ballast provides 300 volts in the secondary. Table II gives the principal characteristics of the lamp.

The J-H1 is physically and electrically interchangeable with the E-H1. It can also be substituted for the A-H1 in most indoor applications. There is usually no need to alter fixtures, but there may be some advantage from the standpoint of efficiency and distribution to do so when using the J-H1. Several fixtures have already been reported specially designed for the J-H1.

When the J-H1 is substituted for the A-H1 (illustrated in Fig. 9), it gives 20 per cent more light and much better color for the same power consumption. Mounting heights of 18 to 35 feet are recommended, but on account of its lower brightness, the J-H1 can sometimes be installed at lower mounting heights. Furthermore, the translucent diffusing shield frequently necessary with some existing A-H1 fixtures can usually be removed, thereby increasing fixture efficiency with the J-H1.[6]

The principal use of the J-H1 will be in the lighting of large industrial areas. Such areas will

TABLE II.—Characteristics of the 400-Watt J-H1 Color Corrected Fluorescent Mercury Vapor Lamp.

Approx. Initial Lumens	18,000
Rated Average Laboratory Life — at 5 or more burning hours per start	4000 Hours
Overall Length	11¼" Maximum
Light Center Length	7" Approximate
Outer Bulb Diameter	Approx. 4¼" at Center
Outer Bulb Glass	#0080 (Lime)
Base	Mogul Screw
Burning Position	Any
Ballast Required	Type H-1—220 Volts Secondary (For normal indoor temperatures. Higher open circuit voltage is required for operation at lower temperatures.)

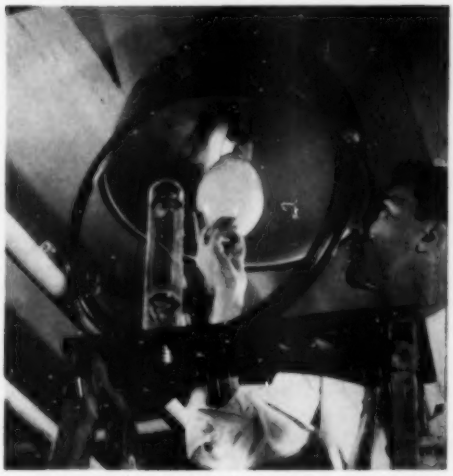

Figure 9. Substitution of J-H1 for A-H1 raises illumination level and provides color correction.

Figure 10. Mixture of 1000-watt incandescent and 400-watt J-H1 color corrected mercury lamps at high mounting height provides good lighting with excellent color quality.

Figure 11. J-H1 lamps at 14-foot mounting height in press room of machine shop. Existing A-H1 fixtures were retained and diffusing rings were removed.

include foundries, press rooms, machine shops, assembly departments, generator stations, (illustrated in Figs. 10 and 11), etc. The J-H1 will also be used for many floodlighting and street lighting applications. For instance, Seaside Heights, N. J., is using it to light the ocean-side boardwalks and in Chicago, Illinois, it is used to light large flower conservatories.[7] It is an excellent light source to flood the fronts of large markets or gas stations and may also have application alone or mixed with other types of lamps for lighting large high ceiling rooms such as waiting rooms in railroad stations. All of these require the long life, high output and high efficiency of the mercury lamp. Now for the first time they can have these advantages with the improved "white" color of light provided by color corrected mercury lamps.

For a look into the future, it is in order to predict that a number of other types of color corrected mercury lamps will follow. All will be alike in depending on a strong source of ultraviolet light such as that supplied by the quartz mercury vapor arc, so as to utilize the phosphor coating to best advantage. There will probably be a 1000-watt lamp, resembling the 400-watt J-H1, and perhaps reflector type mercury lamps which will control the light and provide color correction by means of the phosphor coating.

Summary

New developments such as improved sealing methods, large arc tubes and larger outer bulbs of lime glass have made quartz mercury lamps increasingly desirable for industrial, flood and street lighting. The new magnesium fluorogermanate phosphor has made possible, for the first time, a new line of practical color corrected mercury lamps, such as the 400-watt J-H1, which will greatly widen the acceptance of mercury vapor lighting.

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DISCUSSION

E. A. LINSDAY*: There are three points with regard to this paper which I should like to emphasize:

(1) In view of the starting and, more particularly, the re-starting characteristics of mercury lamps, good practice dictates the use of enough filament lighting to provide safety during periods of delay in the re-starting of the mercury lamps following even a momentary power interruption. Color correction of the mercury source itself in no way obviates this requirement so important in most industrial situations.

(2) Admittedly, the relative overall costs of lighting for various systems will vary somewhat from installation to installation. Nevertheless, all the studies we have made of the relative costs indicate that these are higher for the color-corrected mercury than for other types of mercury, mercury-filament, and even some fluorescent systems. Add

*General Electric Co., Cleveland, Ohio.

the filament lamps needed for protection against power interruption and the cost comparison becomes even more unfavorable.

(3) The third point has to do with the degree of color correction provided in terms of what is accomplished with a combination mercury filament system. In the latter type of installation various proportions have been employed; the most common practice has been to use approximately equal wattages of the two sources with the result that about two-thirds of the lumens are supplied from the mercury and one-third by the filament sources. This is considerably more filament than needed for color equivalence with the corrected mercury lamp.

By making a direct comparison of color-critical samples in adjacent booths with a color-corrected mercury lamp in one, and E-H1 mercury combined with filament in the other, one is able to make a rather critical appraisal of relative color rendition. We find from such tests that with only 15-20 per cent of the total lumens supplied by the filament source the color rendering properties are equivalent to those of the color-corrected mercury lamps.

H. D. Fraser and W. S. Till*: (1) Power failure does not often occur in industry. It is a "bugaboo" which has been raised time and again against a wholly mercury lighting system, and so it may be expected to appear again now that the color corrected fluorescent mercury lamp is being evaluated. Power failure cannot be much of a deterrent to the use of fluorescent mercury lamps by themselves, since there are thousands of straight mercury and fluorescent mercury installations. In such installations there are, of course, usually a few local work lights and emergency lights but these are of no consequence in the overall economics of the system.

(2) Regarding the relative overall cost of light, one must keep in mind the fact that the primary advantage of the J-H1 is in furnishing a long-burning high-intensity source of white light. There is no disputing the fact that ordinary mercury lamps are more economical, but they do not produce white light. Mixtures of mercury and filament lamps can, in some cases, be justified but for more uniform maintenance, there will be a growing preference for a single long-burning light source — the color corrected fluorescent mercury lamp.

(3) In the matter of color equivalence, we have not confined our tests to color boxes — which can be misleading — but have employed typical fixtures for comparison. Based on our tests, we found that the color of our fluorescent mercury lamp is quite closely equivalent to an equal wattage mixture of mercury and filament lamps.

*Authors, Westinghouse Electric Corp., Bloomfield, N. J.

Mercury Vapor Lighting for a Bridge

An illumination level of 2.9 footcandles is obtained on the new Dravosburg Bridge over the Monongahela River, near McKeesport, Pa. Mounted at a height of 31½ feet above the 50-foot roadway on poles spaced 100 feet opposite, the oval-shaped luminaires are equipped with 400-watt 20,000-lumen, E-H1 mercury vapor lamps. ***Photo courtesy Westinghouse Electric Corporation, Cleveland, Ohio.***

Starting Fluorescent Lamps at Low Ambient Temperatures

By R. F. TOWNSEND
H. E. BACHMAN

AS THE ambient temperature decreases below approximately 80°F, the difficulty in starting and maintaining the light output of a fluorescent lamp increases. The majority of standard product fluorescent lamps and auxiliary equipment (starters and ballasts) are designed to give their best performance at 80°F and to provide satisfactory starting and reasonably good maintenance of light output down to 50°F. Today, an increasing number of fluorescent lamps, together with related auxiliary equipment, are being used in both outdoor and indoor applications under much lower ambient temperature conditions than the recommended 50°F. These applications present the question of the minimum ambient temperature at which lamp starting can be obtained with a particular standard production lamp and its corresponding auxiliary equipment.

Such variables as humidity, line voltage, fixture design and the variations in manufacture within the particular design of a lamp and its auxiliary equipment, all play a part in determining the low temperature starting limit. In this paper, an attempt will be made to show the effect of the more important of these variables on lamp starting.

The effect of ambient temperature on light output of fluorescent lamps has been very well covered by other authors[1, 2, 3, 4] — therefore, this paper will cover the aspects of lamp starting only.

A paper presented at the National Technical Conference of the Illuminating Engineering Society, August 27-30, 1951, Washington, D. C. Authors: Commercial Engineering Dept., Westinghouse Electric Corp., Bloomfield, N. J.

Test Conditions

The measurements of lamp starting were made in a walk-in type commercial refrigerator of sufficient size, as shown in Fig. 1, to permit testing of actual lamps and equipment such as would be used in low temperature applications. Temperatures were maintained within ±2°F and all lamps and auxiliary equipment were kept in the refrigerator continuously and allowed to maintain equilibrium with the box temperature.

Various conditions of humidity were encountered in these tests. Conforming to industry practice, all instant start lamps were silicone coated, making

Figure 1. Walk-in type refrigerator used for low temperature testing.

TABLE I.—Rated Open Circuit Voltage of Ballasts at 118 Line Volts.

Lamp Type	
40-Watt T-12 Preheat 40-Watt T-12 LT Preheat	200
90-Watt T-17 Preheat 100-Watt T-17 Preheat	150
40-Watt T-12 Instant Start	450
72" T-12 Slimline—425 Ma	525
96" T-12 Slimline—425 Ma	625
42" T-6 Slimline—200 Ma	450
64" T-6 Slimline—200 Ma 72" T-8 Slimline—200 Ma 96" T-8 Slimline—200 Ma	600
	750

their starting characteristics independent of variations in humidity.[3, 5] Laboratory tests conducted on the types of preheat start lamps used indicate that variations in humidity within the temperature ranges covered will have a negligible effect on lamp starting.

The commercial lead-lag ballasts used in these tests were selected to have both rated open circuit voltage and lamp operating characteristics. The rated open circuit voltage values of these ballasts are shown in Table I.

The ballasts were tested at various ambient temperatures to determine whether their performance was affected by reduced ambient and ballast temperature. No change in performance was observed. This test provided data which were used to determine the open circuit voltage applied to instant start lamps as a function of the primary voltage.

Each group of a lamp type tested consisted of six or more lamps taken at random from several standard production lots of recent manufacture. In all probability, improved future designs will permit easier starting than the data contained herein indicate.

Isolated lamps, as referred to in this paper, are defined as lamps which are separated from any conductive material by at least 18 inches. In the tests where metal fixtures were used, suitable grounding was provided to aid lamp starting.[3, 4]

Starting of Instant Start Type Lamps

In determining the open circuit voltage necessary to start the various instant start type lamps at a specific ambient temperature, the primary voltage was raised in 2-volt increments beginning at 60 volts and the resultant secondary voltage was impressed by means of a switch for each voltage setting. The increment switching method of impressing the starting voltage was used in preference to a continuously impressed gradual rising voltage method because experience has shown the former would more closely simulate actual service conditions. Lamp starting at a given ambient temperature and primary voltage setting was, for the purpose of this test, defined as having been accomplished when both lamps on a lead-lag ballast initiated an arc and operated normally, with no more than two closures of the switch. It was noted that when either lamp was removed from the two-lamp circuit, the starting voltage required for the remaining lamp was no higher than that necessary

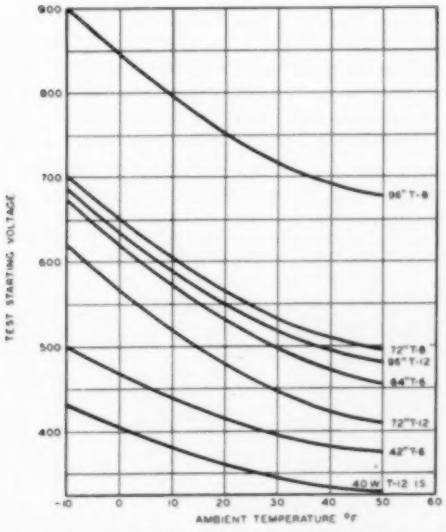

Figure 2. Effect of ambient temperature on starting voltage of isolated instant start type lamps.

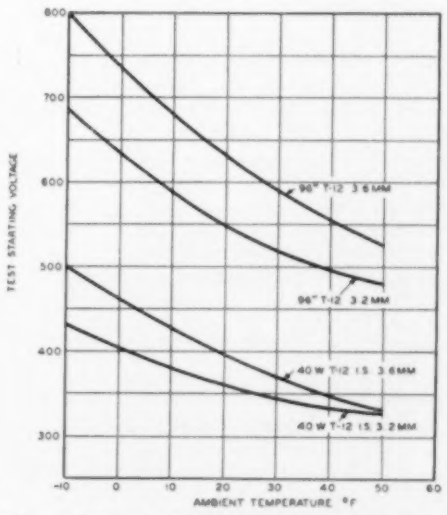

Figure 3. Effect on starting of variation in lamp fill gas pressure.

TABLE II—Effect of Fixture on Test Starting Voltage.

Lamp Type	Fixture	Test Starting Voltage −10°F	+10°F	30°F	50°F
40-Watt T-12 Instant Start	4 lamp glass enclosed cylindrical vertical mounted unit	415	360	340	320
	2 lamp metal enclosed—glass face	400	350	330	320
	Isolated lamps	430	380	345	325
96" T-8 Slimline	2 lamp metal enclosed—glass face	835	750	670	635
	Isolated lamps	900	800	715	675
96" T-12 Slimline	2 lamp metal enclosed—glass face	600	525	460	435
	Isolated lamps	685	590	515	480

to start both lamps. It was also noted that the lag lamp generally is the more difficult to start.

Fig. 2 shows for various instant-start type lamps, the test starting voltage required over the ambient temperature range of −10°F to 50°F to start the hardest starting lamp in each group. This was chosen as the basis for the test starting voltage curve rather than the range in order to simplify the presentation. The range of starting voltages for a given group of lamps became greater at lower ambient temperatures and the effect of ambient temperature on the range was greater for the longer lamps. The maximum spread of test starting voltage occurred at −10°F on the 96T8 group. Here, the individual lamps varied as much as 20 per cent (of maximum value observed) and were uniformly distributed within this range.

In Fig 3 the effect on starting of variation in lamp gas fill pressure is shown for T-12 lamps. From these curves it is obvious that the test starting voltage differential, between the two pressures, isrelatively insignificant at 50°F as compared with −10°F, and that at the lower temperature the higher pressure lamp would require 15 per cent more open circuit voltage. The effect of gas fill pressure is important because it not only explains differences in starting observed between lamps of different manufacturers, and to a lesser extent the variation between lamps of a given manufacturer, but it also shows a means of improving low temperature starting characteristics such as has been done on the T-12 lamps to provide a greater margin of safety.

The data in Table II show lamp startability in grounded metal fixtures as compared with the same isolated lamp of each type used in determining Fig. 2. As might be expected, the starting voltage is reduced when fixtures are used because of the capacitive effect of the conductive material adjacent to the lamp.[3, 4] This effect is considerably more pronounced at lower ambient temperatures and with the greater length lamps.

Starting of Preheat Start Type Lamps

The data presented in Table III show the relative startability at low ambient temperatures of the various preheat lamps tested, with lamps both isolated and in grounded metal fixtures.

In starting the preheat start type of fluorescent lamps, another variable in the form of a starter switch is introduced in the circuit. The starter switch makes preheat lamp starting more complex by comparison to instant start type lamps by the differences which exist in the starting ability of individual starters and by variations between starter designs having the same designation. These starter variables when added to those of the lamps and circuit components make an absolute comparison of preheat lamp startability impractical.[1, 6] Therefore, the data collected from the test were evaluated and condensed into the relative information in Table III.

Reliable starting as designated in Table III pertains to the condition where all lamps tested in the group of each type listed, initiated and maintained a stable arc when tested on a lead-lag ballast. During the tests, starter switch recycling did not present any difficulty. On the other hand, recycling is a function of both the lamp and the starter and it should be noted that recycling can occur in many applications. In some cases, a temporary high lamp voltage at starting may cause recycling — in other cases, it might be due to variations between individual starter designs. Since preheat type lamps should be enclosed for low temperature applications, it is possible that the ambient temperature will increase gradually, as the lamps attempt to start, to the point where recycling lamps may eventually stabilize unless there is a fault in design.

Erratic starting, as designated in Table III, pertains to the condition where one or more lamps in any group tested failed to initiate and maintain a stable arc. It is, therefore, evident that there are

TABLE III.—Relative Test Startability of Preheat Start Type Lamps at 118 Line Volts.

Lamp Type	Lamp Operating Condition	Starter Switch Type	Ambient Temperature 32°F	0°F	−10°F
40-Watt T-12 3.2 mm.	Isolated	Glow	B	A	A
	In fixture	Glow	C	B	A
	Isolated	Thermal	C	B	B
	In fixture	Thermal	C	B	B
40-Watt T-12 (LT) (Low Temperature) 2.8 mm.	Isolated	Glow	C	C	B
	In fixture	Glow	C	C	B
	Isolated	Thermal	C	C	B
	In fixture	Thermal	C	C	C
90-Watt T-17	Isolated	Glow	B	A	A
	Isolated	Thermal	C	C	B
100-Watt T-17	Isolated	Glow	B	A	A
	Isolated	Thermal	C	C	B

Designation "A" — Non starting.
Designation "B" — Erratic starting.
Designation "C" — Reliable starting.

Figure 4. Vertical mounted units each containing eight 40-watt instant start fluorescent lamps provide floodlighting for used car sales lot.

many degrees of erratic starting. Starting was always found to be more reliable at higher ambient temperatures for any specific test combination.

It was noted in the data that the startability of various lamp and starter combinations followed the accepted pattern based on previous experience. As the ambient temperature decreases, starting becomes more reliable with thermal type switches, a lower pressure lamp and a grounded metal enclosed fixture.

Low Temperature Applications of Fluorescent Lamps

In the past few years the application of fluorescent lamps for year round outdoor use has increased rapidly as fixtures specifically designed for this type of service have become available, and as the use of fluorescent lamps as a lighting tool has become more popular.

Various designs of vertical mounted cylindrical glass enclosed units are found in use for floodlighting or "punch" lighting of parking lots, used car lots, service stations, diners, etc. These units are mounted on posts of varying heights or attached to the face of a building and they employ from one to eight fluorescent lamps — the 40-watt instant-start type being the most popular.

Truck, bus and railroad loading platforms are being lighted with fluorescent lamps generally using glass faced enclosed metal luminaires providing high levels of diffuse even illumination over the working area.

Large signboards located adjacent to heavily traveled traffic arteries are being lighted with regu-

Figure 5. Illumination of sign copy containing fluorescent material using 40-watt instant start "Black Light" fluorescent lamps and flashing incandescent lamps.

lar and with "Black Light" fluorescent lamps. These latter signs use principally the 40-watt T-12 instant start 360-BL type lamps, operating continuously, in conjunction with incandescent lamps which operate on approximately a 10-second "on" and "off" timing cycle and provide a spectacular variation effect on sign copy containing fluorescent materials. Double faced multi-colored translucent plastic signs of a smaller variety, suitable for application by retail stores, use various sizes and types of fluorescent lamps mounted in the enclosed area between the sign faces.

Street and tunnel lighting with fluorescent lamps is still in the experimental stage in this country but preheat types and slimline lamps have been used in installations.

Indoor low temperature applications for fluorescent lamps are also expanding. Cold storage warehouses, walk-in refrigerators and self service refrigerated showcases are being lighted with various size preheat and instant start type lamps. When fluorescent lamps are used in these applications, in place of other lamp types previously used, less heat load is placed on the refrigeration system.

Selection of a Lamp for Startability in an Installation

Prior to the selection of a lamp and auxiliary combination for a low temperature application, the low temperature requirements for design must be chosen.

In an indoor low temperature application, such as a cold storage warehouse or a refrigerated showcase, the low ambient temperature point for installation design can be readily determined as it is closely controlled mechanically.

For an outdoor application, the low temperature limit is variable due to climatic changes, adding an additional factor to the problem. In this application, before a lamp and auxiliary combination can be considered, it should first be decided from local temperature data, typical of that shown in Table IV, the low temperature design limit desired. For instance, in a street lighting or equivalent type of installation where lamp starting and restarting in case of power failure should be reliable with all lamps, on any day and at any time of night, the lowest temperature ever recorded in the locality, as shown in Column "A," might logically be selected as the centerpoint for design. In a sign lighting or parking area floodlighting application where the units are started at dusk, usually not the coldest hour of the day, and starting of all lamps under the most extreme low temperature conditions is not an absolute necessity, a compromise can be made on the low temperature design limit and the figures in Column "B" or "C" might be used.

TABLE IV.—U. S. Weather Bureau Temperature Data of Various Cities for 50-Year Period of Record.

Column (A) — Lowest temperature ever recorded — °F.
Column (B) — Daily minimum mean temperature for coldest month — °F.
Column (C) — Daily average temperature for coldest month — °F.

	(A)	(B)	(C)
New York, N. Y.	−14	24.2	30.9
Richmond, Virginia	−3	30.1	38.9
Atlanta, Georgia	−9	35.4	43.8
Miami, Florida	27	61.7	67.9
Fort Worth, Texas	−8	35.8	46.0
St. Louis, Missouri	−22	24.4	32.8
Chicago, Illinois	−23	17.9	25.8
Billings, Montana	−38	14.0	23.7
Seattle, Washington	3	36.0	40.4
San Francisco, California	20	39.7	47.8
Los Angeles, California	28	46.1	56.3

Once the low temperature design limit is decided, the test data, as presented in this paper, will assist in the choice of a lamp and auxiliary combination for practical starting. If absolutely reliable starting is desired for all lamps in an installation, a suitable safety factor must be considered for variations which can exist in the circuit components beyond those found in the limited tests presented in this paper.

In all probability, an installation would not at any one time be likely to have a combination of low line and open circuit ballast voltage, abnormal starters and lamps, and a non-conductive fixture, combined with an ambient temperature below the design limit. Therefore, judgment should be used in the extent of the safety factors which are applied.

If more than a practical starting condition is desired, the resulting starting requirements may prohibit the use of standard auxiliaries. This may make the installation economically unfeasible, and a less costly means may be desired. This may take the form of an incandescent lamp located close to the fluorescent lamp in each fixture, or a pulse of high voltage, the use of a high frequency coil or various other related means.

Conclusions

The data presented clearly shows that starting can be obtained with certain standard fluorescent lamps and auxiliaries over a wide range of ambient temperatures below 50°F. Most instant start lamps under good operating conditions will start down to an ambient temperature of 32°F, with the 40-watt T-12 instant-start lamp being useful at temperatures approaching 0°F. Preheat start type lamps are limited in their low temperature application by the starter switch, but the 40-watt low temperature lamp is useful at temperatures down to 0°F.

Advantages can be found for choosing either instant-start or preheat-start type lamps in a low temperature application. However, the instant-start lamps have the advantage that they can be started at any low ambient temperature by providing the proper open circuit voltage.

The authors gratefully acknowledge the assistance of Mr. H. J. Krautter and Mr. G. R. Mistler in securing the data necessary for the presentation of this paper.

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DISCUSSION

L. R. KEIFFER*: The authors are to be commended for contributing practical information on the starting performance of fluorescent lamps at low temperatures. The table giving temperature data for various cities is particularly appropriate in pointing up the need for considering probable conditions under which a fluorescent lighting system will be expected to operate.

With minor exceptions, the data presented are in agreement with test results at Nela Park. For example, our tests show satisfactory starting of 100-watt T17 lamps at 32F with flow switch starters, and very little difficulty down to zero. We would expect 96-inch T8 lamps to start satisfactorily down to zero and have had no reports of starting difficulties with installations where such temperatures prevail. Quite a number of such installations have given good service for the past three years. On the other hand, our data suggest the possibility of starting trouble with 40-watt instant-start lamps at temperatures around 15F which is higher than the —10F which we believe is indicated by Fig. 2 of this paper.

Our tests confirm that starting at low temperatures is greatly affected by nearby grounded metal surfaces, and we would like to emphasize that the benefit of this starting aid should be used wherever possible.

Although the test data presented seem valid as regards comparisons between lamps on the average, we have found that occasional isolated lamps require much higher starting voltages than indicated here.

Fig. 3 covers the "Effect on Starting of Variation in Lamp Fill Gas Pressure"; the filling pressures shown are 3.2 mm and 3.6 mm. In the family of curves in Fig. 2 the curve for the 40-watt T12 instant-start lamp is the same as the 3.2 mm curve in Fig. 3. We assume that the 3.2 fill gas represents the standard lamps available through distribution channels. Is this correct?

In general, the instant-start ballasts now available start the respective lamps satisfactorily at rather low ambient temperatures and there has been little necessity of special ballasts or special lamps of the instant-start type for low temperature operation. The present situation seems to be quite good; confusion to the customer would undoubtedly occur if either special ballasts or lamps were necessary.

The data presented in this paper undoubtedly apply strictly to the multiple type of lead-lag ballasts. However, the series operation (sequence start) type of ballast for the 40-watt instant-start lamps and for the 72-inch T12 and 96-inch T12 Slimline lamps have obtained such a wide popularity and volume in service that some comment is in order, regarding the use of such ballasts at low temperatures. There seems to be a consensus among lamp manufacturers and ballast manufacturers that these ballasts should not be used at temperatures below 50F due to the adverse effects on the performance of the fluorescent lamps.

H. U. HJERMSTAD*: As stated at the National Technical Conference in Washington, the problem of ballasting the 48T12 lamps for pylon type lights has been a problem of excessive temperatures, so high that they have failed to meet Underwriters' requirements.

A great number of pylon type lights have used series sequence type ballasts which have:

1. Provided the additional open circuit voltage to insure striking the arc under cold operating conditions;
2. Capaciters which are capable of operating at low temperatures.

With this combination the watts loss of the series sequence type ballast was sufficiently low so as to permit the pylon units to pass Underwriters' maximum temperature requirements and at the same time provide a means of starting the lamps at low ambient temperatures.

A number of applications of series sequence type ballasts for outdoor application have been used in conjunction with illumination of signs with the black light type of fluorescent lamp. In addition these same type ballasts have frequently been used as a power source for plastic face signs where a 48T12 lamp has been used as an interior light source.

A number of outdoor applications have been made of the 96T12 lamps using a series sequence type ballast. However, these applications, to my knowledge, have only been in southern climates where the temperature seldom falls below 50 degrees.

A. B. WINTERS**: I would like to congratulate the authors on a very timely and worthwhile paper. I must say their data coincide with the findings of my company back in 1944 and 1945 when we built and installed the first outdoor fluorescent fixture. It was through experiment and the advice of the lamp manufacturers that we found the 40-watt T-12 instant start lamp to be the best lamp to use.

I would like to comment on the authors' method of determining starting. They state that two closures of the circuit for each temperature range were used. I can appreciate the fact that in a walk-in refrigerator where a single lamp is used, starting is extremely important. I would like to touch on a bigger application, the outdoor fixture used primarily not as an illuminant but as a display or "attention getter." These fixtures, employing two, four, or eight lamps, are turned on just before dark. At the instant of closure some of the lamps will start immediately. After a few minutes the ambient temperature will have risen to a point where the remaining lamps will start.

*General Electric Co., Cleveland, Ohio.

*Sola Electric Co., Chicago, Ill.
**Revere Electric Co., Chicago, Ill.

I readily understand that such a condition depreciates the life of the lamp but at least there is some assurance of starting. We have found that the "hard starter" will be less frequent if a non-ventilated fixture is used as ventilation takes away that much needed warmth developed by those lamps that do start.

ABNER BYER*: The authors have presented interesting and valuable data on fluorescent lamp starting at low ambient temperatures. It is unfortunate, however, that the standard cold cathode starting and operating lamp has not been included in this report. Based on the many thousands of cold cathode lamps used for outside uses, for display and illumination, it is our understanding that the cold cathode lamp is the fluorescent lamp most readily adapted for low temperatures. With the cold cathode lamp the required higher starting voltage can be utilized without affecting lamp life. Of course, once the cold cathode lamp is started the factors of fluorescent light output between the ends of the lamp are the same as other fluorescent lamps.

R. F. TOWNSEND and H. E. BACHMAN**: The authors wish to thank those people who were interested enough in the contents of this paper to submit a written discussion.

In order to present more clearly our answers to the questions posed in the various discussions, we shall take each in the order presented.

Discussion #1. — It is possible, in reply to the information in the second and fourth paragraphs, that there will be some minor exceptions in starting data as compared to that received by other laboratories. This is due to the large number of variables in lamps and auxiliaries affecting starting which can exist between manufacturers or to a lesser extent within different groups of products produced by the same manufacturer.

In answer to Mr. Kieffer's question on lamp fill gas pressure, at the time these tests were run, it was found that a 3.2 mm gas fill pressure was prevalent in most brands and types tested. Some lamps contained pressures as high as 3.6 mm which was the basis for the decision to use this pressure as a comparison in Figure 3.

*Cold Cathode Lighting Corp., Long Island City, N. Y.
**Authors.

At the time the starting tests were performed, it was decided to limit the data to the use of the well established standard lead-lag type ballasts because of the variety of designs and circuits which existed in series sequence types and the understanding received from manufacturers of these ballasts that they were not generally satisfactory for use below 50F. It is our understanding now that a special design of series sequence ballasts can be made available for starting and operations below 50F. In Mr. Hjermstad's discussion, he points to the modifications required for a low temperature series sequence ballast.

Discussion #2. — With the present industry interest in series sequence type ballasts, it is good to know that this design can be adapted for low temperature applications below 50F. As mentioned above, in reply to Mr. Kieffer, it was the understanding at the time the tests were made that the series sequence ballast was not recommended for operation in ambient temperatures below 50F. It is still the authors' understanding that the present standard series sequence ballasts also have this limitation.

Discussion #3. — It was necessary to establish the arbitrary maximum of two switch closures for reliable starting in order that the absolute starting voltage data for the various lamps be on the same basis. It is possible in an enclosed multiple lamp unit, to aid the harder starting lamps to ignite by the rise in ambient temperature occasioned by the operation of the easier starting lamps. If an instant start lead-lag circuit is used, the impressed open circuit voltage will have no effect on the life of the harder starting lamps which may take a few minutes to start. In a preheat circuit, there will be an effect on the life of the harder starting lamps, the extent of which will depend on the number of closures of the starting switch before the stable arc is struck between the lamp electrodes.

Discussion #4. — The authors have found from field and laboratory experience that hot cathode fluorescent lamps, particularly the instant start and Slimline types, are excellent from the viewpoint of starting and performance in low temperature applications. On this basis, it was felt that information on starting of hot cathode lamps at low ambient temperatures should be compiled for public information.

Perhaps the title of the paper is a little misleading since it was limited to data on hot cathode lamps.

TO DRAMATIZE their building, the Denholm and McKay department store, Worcester, Mass., floodlighted the limestone facing to a level of about ten footcandles. Store officials obtained permission to use four street lighting poles on which they mounted twelve general purpose, heavy duty floodlights with lightly stippled door glass and 1,000-watt multiple general lighting lamps. Pipe extensions and three-armed brackets were attached to the poles to raise the lights above the marquee.
Photo courtesy General Electric Co., Schenectady, N. Y.

Object-Color Changes From Daylight to Incandescent Filament Illumination

By HARRY HELSON
DEANE B. JUDD
MARTHA H. WARREN

IT IS KNOWN that the eye adapts to a considerable extent to counteract changes in the quantity and quality of different sources of illumination but its powers of adaptation are not unlimited. The new state of adaptation itself, along with the change in spectral energies reaching the eyes, results in changes in the colors of objects as the source is changed. The present report is based upon a study of the colors of Munsell samples under Macbeth daylight and incandescent filament light (color temperature 2854°K) with a view toward formulating a quantitative theory for predicting the changes in passing from one to the other. A simplified Young-Helmholtz theory predicts fairly accurately the colors of the samples under source *A* from a knowledge of their chromaticity coordinates for that source. The theory does not attempt to predict color changes due to the influence of backgrounds of different reflectances but data for white, gray, and black backgrounds are presented. The quantitative theory is based upon the changed chromatic adaptation of the eye under source *A* as compared with its adaptation under source *C*.

When an observer takes an array of colored objects from natural daylight into a room illuminated by an incandescent filament source, he notices immediately that the colors perceived to belong to the objects have changed to a marked degree. The blues have become darker and much less saturated; the greens, yellower; and the purples much redder. These changes can be predicted by computation from the spectral reflectances of the objects by means of the C.I.E. standard observer by changing from standard source *C* (representative of average daylight) to standard source *A* (representative of an incandescent filament source). These predictions hold good for the daylight adapted eye. Unfortunately, the observer's eye begins to change almost immediately on entering the artificially illuminated room, and after five minutes or so the eye increases its sensitivity to the short-wave part of the spectrum so that many of the objects are perceived to have approximately the same colors that they had in daylight. This is known as color constancy. Thus, the blue objects during this period of adaptation to the reddish-yellow of the incandescent filament illumination regain some of the saturation that they had in daylight. The greens change back from yellowish-greens to greens or even bluish-greens; but the purples lose only a small part of the red that they gained in the transition from daylight to incandescent filament lighting.

The perception of the colors of objects in a room lighted by chromatic illumination is thus a combination of two effects; the first arising from the changed spectral character of the radiant energy leaving the objects, complicated, but known; the second arising from the changed state of adaptation of the eye, complicated, and not fully known.

The present study, carried out with the support of a grant from the I.E.S. Research Fund, is intended to evaluate the influence on color perception of the changed state of chromatic adaptation in passing from daylight to incandescent filament illumination. If this influence can be evaluated, the results will also be applicable to fluorescent lamps, such as the warm-white, producing about the same chromatic adaptive state as the incandescent filament source. Of course, the spectral composition of the warm-white fluorescent lamp will cause the radiant energy leaving the objects to be markedly different from that leaving objects illuminated by the incandescent filament source, but as noted above, this part of the problem has already been solved by means of the C.I.E. standard observer and coordinate system.

1. Method

In order to obtain reliable estimates of the colors of a standard set of objects such as the Munsell color chips, it is necessary to train a group of observers having normal color vision to report in

A paper presented at the National Technical Conference of the Illuminating Engineering Society, August 27-30, 1951, Washington, D. C. Authors: Harry Helson, Professor of Psychology, University of Texas; Deane B. Judd, Physicist, National Bureau of Standards; Martha H. Warren, Research Assistant, Brooklyn College. This study was made at Brooklyn College during the 1950-51 academic year. Work done under Project No. 11 of the I.E.S. Research Fund.

terms of some color system with which they have become familiar. The color system chosen for this purpose was a modification of the Munsell system. It consisted of a description of color in terms of hue, lightness, and saturation as usually defined. Lightness and saturation (Munsell value and chroma) were estimated on an eleven-point scale ranging from 0 to 10 with 5 denoting medium lightness or saturation. Observers were permitted to make their estimates in half or quarter unit steps and often did so, so that in actual use the lightness-saturation scale was more than an eleven-step scale. Hues were denoted in terms of the four unitary (psychologically primary) qualities of red, yellow, green, or blue and their combinations. Thus a hue which seemed to have equal parts of red and yellow was called yellow-red (*YR*). A hue with equal parts of red and yellow-red was called red yellow-red (*RYR*) while equal amounts of yellow and yellow-red were called yellow yellow-red (*YYR*). Binary hues in the other regions of the color circle (or color "mixtures") such as yellow and green, green and blue, blue and red were similarly described. The continuum extending from one primary to the adjacent primary on the hue circle (red to yellow, yellow to green, green to blue, blue to red) was divided into eight parts, each part representing an equal amount of the next primary. Thus, to compute the average hue from a number of estimates of the same chip, a yellowish red was considered as having one part of yellow to six parts of red. The next step, a red yellow-red, was regarded as having two parts of yellow to six parts of red. This notation provided 32 hue steps from red through yellow to green to blue and back to red. The numerical notation was for purposes of computation only since the observers' estimates of hue were always in terms of the qualitative categories described above. This numerical scale also made it possible to translate observers' reports into Munsell notation which differs from ours in that the Munsell system employs purple (P) as a fifth primary hue whereas in the system used by the observers purple is regarded as a binary hue with equal amounts of red and blue. Furthermore, our observers' unitary blue did not correspond with the Munsell 5.0 blue which was almost always regarded as somewhat on the greenish side while Munsell 5.0 PB was almost always reported as pure, unitary blue. Thus our observers' estimates were based on an intuitive apprehension of the unitary hues, red, green, blue, yellow, and their mixtures.

Since the observers were inexperienced to begin with, it was necessary to instruct them regarding the meaning of the terms hue, lightness, and saturation and their specification in terms of the system just described. For this purpose the Munsell Book of Color was employed both to acquaint them with these three basic attributes of color and to demonstrate how they could be ordered on scales of equal-appearing intervals. Thus it was demonstrated how the difference in lightness or saturation between scale steps 3 and 4 was equal (or supposed to be equal) to the difference between steps 5 and 6 or any other two adjacent steps. The observers were then required to place Munsell color chips on the Student Charts and to compare their ordering with the Munsell Book of Color. This procedure was most effective in teaching the observers not only how to order colors with respect to hue, lightness and saturation but also served to direct their attention to differences in colors. Next the observers were required to place a single chip on a chart without the aid of a range of chips to establish a continuum. This meant that the observer had to be able to recognize a chip's Munsell value and chroma without regard to lighter or darker, more or less saturated chips to guide him. Finally, the observers were required to estimate the hue, lightness and saturation of the chips without reference to the Munsell Book of Color, thus anticipating what would be required in actual observations. When the observers were able to designate the chips to within one step of Munsell hue, value, and chroma, they were considered sufficiently trained to begin regular observations. It required about 8 hours of training and practice as just described for the observers to reach the criterion demanded for participation in this study. Training was conducted in a room having a good northern exposure giving a good approximation to standard source *C*. Out of the 9 college students trained in judging the colors, the 6 best were chosen as observers in the final experiments. It should be emphasized that our observers were not trained to try to remember how the chips looked in daylight or what they had called them during their practice periods. They were instructed, after they had attained proficiency in estimating the three Munsell attributes, to make the best estimates of the color chips as they looked under the conditions of this study. That memory played some part in the final

TABLE I.—Reflectance and Photometric Brightness of the Backgrounds.

Background Reflectance		Photometric Brightness (footlamberts)	
		Source *C*	Source *A*
Black	0.03	2.2	1.7
Gray	0.21	15.4	12.0
White	0.78	57.2	44.2

TABLE II.—Hue, Lightness and Saturation of 60 Munsell Samples on White and Black Backgrounds Under Sources *C* and *A*

Munsell renotation		Judgment Under Source *C*						Judgment Under Source *A*					
		White Background			Black Background			White Background			Black Background		
H	V/C	H	S.D.$_M$	L/S	H	S.D.$_M$	L/S	H	S.D.$_M$	L/S	H	S.D.$_M$	L/S
3.5R	2.3/2.2	8.7R	4.5	1.8/1.2	4.6R	1.8	3.0/3.4	2.5RP	13.8	2.1/2.4	10.0R	1.1	2.9/3.5
3.5R	4.06/4.8	8.7R	1.4	3.8/4.0	4.6R	1.5	4.8/3.9	4.6R	2.2	3.9/4.5	4.6R	1.5	5.3/4.2
5.0R	4.20/12.8	4.6R	0.4	5.0/11.8	5.4R	0.4	5.5/12.0	5.8R	0.5	5.5/12.7	5.4R	0.8	6.7/11.8
3.5R	6.96/7.0	0.8R	1.3	5.3/4.9	6.5R	1.4	6.5/5.1	8.3R	1.4	5.4/4.8	8.7R	1.4	7.0/5.0
3.5R	7.97/3.4	1.7R	1.0	7.5/4.0	2.9R	1.4	7.5/4.0	5.8R	0.9	7.1/4.5	5.4R	0.8	7.6/3.7
9.5R	5.06/4.9	2.5YR	2.1	4.7/4.7	1.7YR	2.4	6.0/4.3	1.7YR	1.7	4.6/3.5	2.9YR	1.8	5.8/4.3
4.5YR	2.43/1.7	8.5Y	9.9	1.5/2.0	9.6YR	2.8	3.1/3.9	3.8YR	5.3	1.8/1.6	6.7YR	2.1	3.6/3.6
4.5YR	4.92/4.6	8.7YR	2.9	4.1/3.9	2.1YR	2.4	6.2/4.2	6.2YR	1.7	4.5/3.8	7.1YR	1.4	5.4/4.3
6.0YR	6.20/11.5	5.0YR	1.7	5.0/9.5	8.7YR	2.1	6.1/8.5	4.6YR	1.6	5.2/9.0	5.4YR	1.2	5.9/9.3
4.5YR	7.03/8.2	5.0YR	1.7	5.5/5.3	7.9YR	2.6	5.8/6.2	5.4YR	1.2	6.1/6.5	8.3YR	1.1	6.3/6.9
4.0YR	8.03/3.4	0.8YR	2.1	7.1/3.7	2.5YR	3.1	7.7/3.3	5.0YR	2.2	7.0/3.7	2.5YR	2.6	7.2/4.0
10.0YR	5.08/4.4	9.2YR	3.0	4.4/3.7	2.9Y	1.7	5.6/4.0	5.8Y	4.1	4.4/4.0	0.8Y	2.0	5.2/4.8
5.0Y	2.53/1.4	9.6YR	5.9	1.8/2.2	4.6GY	1.9	3.0/3.5	8.0Y	4.6	1.2/1.4	6.2Y	4.5	3.6/3.8
5.5Y	4.07/3.9	5.8GY	2.0	3.6/4.8	4.6Y	2.5	4.7/4.5	7.1GY	1.5	3.8/5.4	7.9Y	3.2	4.5/4.5
5.5Y	7.88/12.3	5.6Y	1.2	5.8/8.7	4.6Y	1.0	6.0/9.8	8.3Y	0.9	5.7/7.3	5.8Y	1.3	6.7/8.2
5.5Y	7.90/8.3	7.1Y	0.8	6.4/6.8	5.8Y	1.1	6.6/7.2	5.8Y	1.3	5.6/6.2	4.6Y	0.4	6.6/8.2
5.0Y	7.80/5.5	5.4Y	1.4	5.7/4.6	5.4Y	0.8	6.7/5.2	7.1Y	1.4	5.8/4.8	7.5Y	1.6	7.1/5.7
10.0Y	4.37/3.7	8.3GY	1.5	4.6/5.8	4.6GY	1.9	5.0/4.9	9.2GY	1.4	5.0/4.7	5.8GY	1.7	5.2/4.5
5.5GY	2.5/2.0	2.1G	0.9	1.5/2.3	0.8G	0.5	3.8/4.4	1.9G	1.0	1.3/1.5	0.4G	0.4	3.3/3.9
5.0GY	5.10/5.4	10.0GY	0.0	4.8/6.1	6.7GY	1.8	5.7/6.0	10.0GY	0.6	4.8/6.0	7.5GY	1.1	5.6/5.7
4.0GY	6.97/9.5	7.5GY	1.9	5.5/7.8	4.2GY	1.7	6.4/8.2	9.6GY	0.8	5.4/8.2	4.6GY	1.8	6.7/7.2
4.5GY	8.06/8.6	5.0GY	1.7	6.1/8.0	2.1GY	1.7	7.0/6.6	5.8GY	1.7	6.4/6.7	2.5GY	2.4	6.9/7.2
6.0GY	8.07/3.6	1.2G	0.9	7.0/3.8	1.7GY	1.7	7.6/3.7	1.2 G	0.5	6.9/4.0	7.9GY	2.3	7.7/3.1
10.0GY	5.0/4.3	1.7G	0.5	4.6/4.5	10.0GY	0.6	5.8/5.2	2.9G	1.2	4.5/5.9	2.5G	1.1	5.7/4.7
7.0G	2.22/2.4	3.3G	1.0	1.9/2.0	3.3G	0.5	3.7/5.7	8.0BG	5.1	0.9/0.7	3.3G	0.5	3.0/5.2
5.0G	4.86/4.7	4.2G	0.6	4.8/5.2	4.6G	1.0	5.5/4.5	5.0G	0.9	4.5/6.2	5.0G	1.3	5.6/5.7
5.0G	4.89/8.1	5.0G	0.6	5.2/8.3	7.0G	1.2	6.0/5.9	4.6G	0.8	5.0/7.9	3.7G	0.5	5.7/7.2
7.0G	7.05/6.2	3.3G	1.1	6.0/5.1	7.0G	1.2	7.0/5.0	1.5BG	3.5	5.5/6.2	3.7G	1.6	5.6/5.1
6.0G	8.66/2.7	4.6G	1.7	8.2/3.4	3.6BG	1.9	9.2/1.8	2.5BG	2.5	7.7/4.3	5.8GY	3.1	8.2/2.7
10.0G	3.21/4.7	7.0G	0.9	3.4/5.6	8.4G	0.7	5.9/7.3	7.0G	1.4	3.4/6.0	8.4G	0.7	4.7/7.5
4.5BG	2.24/2.5	10.0GY	7.9	1.7/2.2	5.0G	1.1	3.9/5.9	8.5BG	7.5	1.0/0.8	8.4G	1.5	3.3/4.2
5.5BG	4.31/4.0	1.0BG	2.3	4.6/5.0	4.0BG	0.8	5.2/4.6	1.0B	3.8	4.5/5.7	3.0BG	3.2	5.2/4.7
5.0BG	5.13/6.4	2.5BG	2.2	5.0/7.2	5.0BG	1.7	5.3/6.6	3.6BG	1.5	4.5/6.4	5.0BG	2.5	5.8/5.8
2.0BG	6.37/4.5	5.0G	2.6	4.9/5.3	3.0BG	2.5	6.8/4.7	3.0BG	6.0	5.4/5.9	7.0G	2.5	6.7/4.6
4.5BG	7.22/3.3	9.0BG	5.0	6.1/4.7	2.3B	5.3	8.1/2.8	5.0BG	4.5	5.7/4.8	3.0BG	5.8	7.5/37
9.0BG	4.14/4.0	5.5BG	5.0	4.2/5.2	3.8B	4.7	5.8/4.6	8.0BG	4.2	4.1/5.0	8.0BG	4.5	5.1/4.2
5.0B	3.13/2.3	2.0B	7.0	3.1/3.0	4.0B	3.8	4.5/3.3	7.0B	4.7	2.0/2.5	4.8B	3.3	4.2/2.8
5.5B	4.98/5.1	7.6B	1.0	4.7/5.2	7.6B	1.8	6.2/5.0	7.0B	0.8	4.9/5.7	8.0B	1.3	5.8/4.8
5.0B	4.96/6.8	7.6B	2.3	5.0/7.5	6.2B	2.8	5.7/6.8	8.0B	1.3	5.0/6.0	8.5B	1.8	5.7/6.2
5.5B	6.11/6.4	6.0B	3.0	5.7/6.0	6.0B	3.3	6.2/6.3	8.5B	1.0	5.3/6.5	7.0B	3.0	6.6/5.2
4.0B	8.15/2.2	10.0B	0.8	7.0/3.2	7.6B	9.3	9.0/1.6	8.0B	2.0	7.6/3.7	7.3PB	11.3	8.7/1.7
10.0B	4.15/4.0	10.0B	1.5	4.4/4.0	10.0B	3.3	5.7/4.3	1.6PB	1.3	3.9/4.2	10.0B	1.7	5.3/3.3
4.5PB	2.15/2.6	3.0PB	0.8	1.5/2.8	7.0PB	4.8	2.9/3.4	6.4PB	2.8	1.5/1.5	7.5PB	2.3	3.0/4.0
4.5PB	3.26/9.3	2.5PB	1.3	4.7/5.2	7.5PB	3.8	5.1/4.8	5.0PB	0.7	3.8/3.4	5.0PB	1.3	5.2/3.2
5.0PB	4.23/4.2	2.5PB	0.7	4.7/9.8	2.0PB	0.3	5.3/8.7	2.5PB	0.7	4.7/9.7	1.6PB	0.0	4.7/7.8
5.0PB	6.27/7.2	3.0PB	0.8	6.0/5.8	4.8PB	0.8	5.4/5.7	4.6PB	0.8	5.3/5.1	6.4PB	1.3	6.8/4.2
5.0PB	8.26/3.c.	6.0PB	1.0	7.7/4.3	6.2PB	5.2	9.2/0.9	4.8PB	0.8	7.8/4.0	0.5B	17.2	9.3/0.8
10.0PB	4.13/4.6	9.5PB	0.7	4.2/5.3	1.2P	1.8	5.8/5.3	1.2P	0.8	4.0/4.5	1.2P	0.8	5.0/4.2
5.0P	2.24/3.3	1.0PB	8.3	1.8/2.7	5.5P	3.0	3.6/4.1	5.0P	3.5	2.0/2.4	4.0P	1.8	2.9/4.2
5.0P	4.95/4.7	2.8P	1.5	5.2/4.7	5.5P	1.8	6.2/4.7	3.3P	2.0	4.6/5.4	7.4P	2.5	6.1/4.3
5.5P	4.08/12.6	5.0P	2.0	4.8/8.6	8.8P	2.0	5.0/7.0	3.5RP	1.5	5.0/9.5	5.0RP	1.5	5.7/7.8
5.5P	7.05/6.4	2.5P	2.2	6.1/5.5	0.8RP	2.8	7.5/4.6	1.8RP	2.2	5.7/5.0	7.2RP	1.8	7.3/5.3
5.0P	8.02/4.7	3.3P	2.7	7.3/4.7	3.4RP	3.3	8.3/2.1	1.5RP	2.2	7.0/4.7	9.2RP	2.0	8.1/3.2
10.0P	3.16/4.3	10.0P	3.3	3.2/4.8	10.0P	2.8	4.2/5.7	10.0P	2.2	3.7/5.9	4.5RP	2.2	4.0/4.7
6.5RP	2.27/2.3	5.0PB	12.5	1.4/1.6	3.5RP	1.8	3.2/3.3	2.6RP	3.3	2.5/3.2	8.8RP	0.8	3.0/3.8
4.0RP	4.32/4.4	8.0P	2.7	4.1/3.6	6.6RP	2.0	5.0/5.1	3.5RP	2.0	3.9/3.7	8.0RP	1.5	5.4/3.2
5.0RP	4.29/10.7	4.5RP	0.8	4.7/7.2	4.5RP	1.5	5.4/8.3	8.8RP	1.5	5.5/9.6	9.2RP	0.7	5.7/8.7
4.5RP	6.32/8.4	5.5RP	1.8	5.2/6.1	7.2RP	1.5	6.4/6.3	8.8RP	0.8	5.5/5.5	1.0R	2.3	6.3/6.5
5.5RP	8.08/2.6	3.5RP	2.5	7.2/3.3	10.0RP	1.2	9.2/1.8	8.0RP	3.3	6.7/3.7	0.8YR	2.3	8.3/3.0
10.0RP	5.30/4.2	0.5R	5.8	4.2/3.1	1.0R	1.8	6.6/4.0	0.5R	2.1	4.7/3.2	2.0R	3.8	5.2/4.2

estimates cannot be denied, but a naive, phenomenological approach was encouraged during the final observations.

The observations were made in a light-tight booth lined with a good non-selective white cardboard throughout. The light sources were suspended from the ceiling by means of a pulley so that they could be adjusted to give the desired illumination on a shelf upon which the color chips were displayed. Macbeth Daylight lamp installations containing two 1000-watt incandescent lamps with appropriate blue filters to approximate standard source *C* (6700°K) and a standard 500-watt incandescent lamp operated at the correct current to yield standard source *A* (2854°K) served as the two sources of illumination. Observers were fully adapted to the source of illumination under which the chips were viewed by remaining in the booth for five minutes before the observations began. The chips were viewed successively on each of three non-selective backgrounds having reflectances of 3, 21 and 78 per cent respectively.

Table I gives the six conditions under which the observations were made. The illumination levels were 73 footcandles with the source approximating daylight and 57 footcandles with the source ap-

TABLE III.—Observed and Theoretical Hues and Saturations of Munsell Samples on Gray Backgrounds Under Sources *C* and *A*.

Munsell renotation		Observer's Estimate		Departure from Color Constancy *A* - *C*		Theoretical Estimate	Theoretical Departure *A* - *C*	
		Under *C*	Under *A*					
H	V/C	H S	H S	ΔH	ΔS	H S	ΔH	ΔS
5.5R	2.3/2.2	6.5R / 3.2	6RP / 3.5	−10.5	.3	4.8R / 3.0	1.3	.8
5.5R	4.06/4.8	5.7R / 4.1	7.8R / 1.7	2.1	−2.4	5.3R / 5.7	1.8	.9
5.0R	4.20/12.8	5.0R /12.5	5.3R /13.6	.3	1.1	6.3R /16.1	1.3	3.3
5.5R	6.96/7.0	4.7R / 5.3	8.4R / 5.5	3.7	.2	6.2R / 8.0	2.7	1.0
5.5R	7.97/3.4	1.0R / 4.2	6.1R / 3.6	5.1	−.6	5.4R / 3.9	1.9	.5
9.5R	5.06/4.9	0.4YR / 3.8	2.4YR / 4.3	2.0	.5	1.6YR / 5.8	.4	.7
4.5YR	2.43/1.7	8.7YR / 3.3	9YR / 3.2	.3	−.1	3.8YR / 2.1	.4	.7
4.5YR	4.92/4.6	6.7YR / 3.8	8YR / 4.3	−.7	.5	4.8YR / 5.2	.3	.6
6.0YR	6.26/11.5	7.1YR / 9.7	5.6YR / 9.8	−1.5	.1	6.4YR /12.2	.7	.5
4.5YR	7.03/8.2	6.9YR / 6.3	5.7YR / 6.3	1.2	.0	4.9YR / 8.9	2.1	.9
4.0YR	8.03/3.4	0.2YR / 3.3	4.3YR / 3.7	4.1	.4	4.8YR / 3.7	.8	.3
10.0YR	5.08/4.4	0.3Y / 3.6	3.7Y / 3.6	3.4	.0	2.5Y / 4.6	2.5	.2
5.0Y	2.53/1.6	5.4GY / 2.8	1.9GY / 2.9	−3.5	.1	2.3Y / 1.6	−2.3	.2
5.5Y	4.07/3.9	4.3GY / 4.4	5.7GY / 5.5	1.4	.1	9.0Y / 3.8	3.5	−.1
5.5Y	7.88/12.3	5.5Y /10.7	5.5Y / 9.4	.0	−1.3	9.5Y /11.9	4.0	−.4
5.5Y	7.90/8.3	0.9G / 4.5	1.9G / 5.6	1.0	1.1	2.7G / 5.3	2.7	1.0
7.0G	2.22/2.4	2.8G / 4.2	1BG / 3.9	8.2	−.3	2.5BG / 2.8	5.5	.4
5.0G	4.86/4.7	3.1G / 4.2	4.3G / 5.9	1.2	.8	9.7G / 6.2	4.7	2.5
5.0G	4.89/8.1	3.6G / 8.9	4.6G / 8.3	1.0	.3	10.1G /10.1	5.0	2.0
7.0G	7.05/6.2	4.3G / 5.4	5.0G / 5.2	.7	−.2	2.5BG / 7.8	5.5	1.6
10.0G	3.21/4.7	4.6G / 6.8	3.3G / 6.2	−1.3	−.6	4.0BG / 5.4	4.0	.7
4.5BG	2.24/2.5	6G / 4.3	8.5BG / 3.5	12.5	−.8	8.7BG / 2.5	4.2	.0
5.5BG	4.31/4.0	3BG / 4.8	7BG / 5.5	4.0	.7	8.8BG / 4.8	3.3	.8
5.0BG	5.13/6.4	7BG / 7.2	5BG / 6.9	.0	−.3	8.9BG / 7.5	3.9	1.1
2.0BG	6.37/4.5	2.5BG / 5.3	3BG / 5.0	.5	−.3	5.1BG / 5.9	3.1	1.4
4.5BG	7.22/3.3	9BG / 4.2	6BG / 4.5	−3.0	.3	7.8BG / 4.2	3.3	.9
9.0BG	4.14/4.0	10BG / 4.7	1BG / 5.0	−9.0	.3	2.5B / 4.7	3.5	.7
5.0B	3.13/2.3	4B / 3.7	4B / 4.1	0.0	.4	7.1B / 2.7	2.1	.4
5.5B	4.98/5.1	9B / 5.4	9B / 5.9	0.0	.5	7.2B / 6.0	1.7	.9
5.0B	4.96/6.8	9B / 6.7	10B / 7.5	1.0	.8	8.2B / 8.1	3.2	1.3
5.5B	6.11/6.4	5PB / 6.3	7B / 6.4	−3.5	.1	7.4B / 7.6	1.9	.8
4.0B	8.15/2.2	8B / 2.9	7.5B / 2.4	−.5	−.5	5.0B / 3.1	1.0	.9
10.0B	4.15/4.0	10B / 5.0	1PB / 5.0	1.0	.0	2.5PB / 4.1	2.5	.1
4.5PB	2.15/2.6	1.5PB / 3.5	2.5PB / 3.4	1.0	−.1	6.0PB / 2.8	1.5	.2
5.0PB	4.23/4.2	4PB / 5.4	4.5PB / 4.9	.5	−.5	6.3PB / 4.6	1.3	.4
4.5PB	3.26/9.3	2.5PB / 9.5	2.5PB / 9.5	.0	.0	6.8PB /11.4	2.3	2.1
5.0PB	6.27/7.2	4PB / 5.7	5.5PB / 5.5	−1.5	−.2	6.5PB / 8.0	1.5	.8
5.0PB	8.26/3.0	1.5PB / 2.5	2.5PB / 1.3	−1.0	−1.2	6.6PB / 3.5	1.6	.5
10.0PB	4.13/4.6	9.5PB / 5.4	0.5P / 5.4	1.0	.0	3P / 4.9	3.0	.3
5.0P	2.24/3.3	10P / 3.8	1RP / 4.4	1.0	.6	9.7P / 3.7	4.7	.4
5.0P	4.95/4.7	3P / 5.0	7P / 4.9	4.0	−.1	7.9P / 5.6	2.9	.9
5.5P	4.08/12.6	8P / 7.8	3.5RP / 7.2	5.5	−.6	9.5P /14.5	4.0	1.9
5.5P	7.05/6.4	9.5P / 4.9	5.5RP / 5.6	6.0	.7	8.8P / 7.9	3.3	1.5
5.0P	8.02/4.7	8P / 4.2	6RP / 4.0	8.0	−.2	7.1P / 5.4	2.1	.7
10.0P	3.16/4.3	8P / 4.5	2RP / 5.7	4.0	1.2	2.4RP / 5.4	2.4	1.1
8.5RP	2.27/2.3	5P / 3.3	3.5RP / 3.7	8.5	.4	9.4RP / 3.0	2.9	.7
4.0RP	4.32/4.4	3.5RP / 4.5	5RP / 4.5	1.5	.0	7.2RP / 5.6	3.2	1.2
5.0RP	4.29/10.7	6RP / 8.2	9RP / 9.0	3.0	.8	7.9RP /13.3	2.9	2.6
4.5RP	6.32/8.4	6RP / 6.4	10RP / 6.3	4.0	−.1	7.5RP /10.4	3.0	2.0
5.5RP	8.08/2.6	7.5RP / 3.0	5.8R / 3.6	8.3	.6	7.5RP / 3.2	2.0	.6
10.0RP	5.30/4.2	6.5RP / 3.4	1R / 4.0	4.5	.6	2.7R / 5.2	2.7	1.0

proximating source *A*. The difference of about 28 per cent between the two types of illumination being studied is not great enough to be responsible for the color differences observed. Previous studies have shown that it takes changes in illumination levels of the order of 100 to 1 to cause appreciable shifts in hue under the conditions of this study (Helson and Jeffers, 1940).

The samples measured 1" x 1" and were mounted in cardboard holders similar to the background. They were placed a few inches apart on a shelf in the booth and 11 were exposed in random order during each observation. This was for the purpose of providing a variety of colors in the field of view both to simulate natural conditions of vision and to enable the observers to make their judgments with a number of samples serving as frames of reference. The samples were selected as follows: from the Munsell Book of Color, ten major hues were selected at high value and high chroma, ten at high value and medium chroma, ten at medium value and high chroma, ten at medium value and medium chroma, and ten at low value and low chroma. Ten equally spaced intermediate hues were selected at medium value and medium chroma. Three nearly non-selective samples were also ob-

served but they are not included in the results because according to the simple theory tested here they should remain nearly achromatic in the two sources. Actually they were reported as having hues of very low saturation, depending largely on the background against which they were viewed.

2. Results and Discussion

Table II shows the average results of the six observers for the 60 Munsell samples judged under sources *C* and *A* on white and black backgrounds. Standard deviations of the means of the hue judgments are also given. It will be noted from this presentation of data on the two backgrounds representing extremes in reflectance and therefore giving maximal background effects, that the differences in color due to background are as great as those corresponding to the change from daylight to incandescent filament illumination. This is in keeping with previous findings (Helson, 1938) and shows that hue and saturation of an object depend importantly upon the relation of its reflectance to adaptation-reflectance. Adaptation-reflectance is a weighted mean of the reflectance of all objects in the field of view and is largely determined by the background (Judd, 1940). Since we are primarily interested in the effect of the source in this study we pass over further consideration of background effects at this time.

Table III shows for the gray background the hues and saturations reported under sources *C* and *A* and the differences caused by changing the adaptation of the observers from daylight (*C*) to incandescent filament illumination (*A*). If it were true that the colors of objects remain completely independent of the source (so-called perfect color constancy) these differences would fail to differ significantly from zero. Statistical test of the differences between the hues reported under the two sources reveals that they are very highly significant, the t-value for the obtained differences being 6.7 which is nearly three times the value of 2.66 necessary for significance at the one per cent level of confidence. While many of the differences are small because some colors remain practically unchanged under the two sources, the changes in the rest of the samples are sufficiently great relative to individual-observer differences to yield overall significance statistically. Note particularly how the purple samples change to red-purple.

3. Theory

It is known that the complete theory of object-color perception is very complicated (Judd, 1940) and must take account of the background as well as the object and the spectral composition of the illuminant if the adaptation of the eye is to be included in the theory. There is considerable experimental evidence to support the view that the state of chromatic adaptation of the observer's eye may be taken at least approximately into account by means of the three-components, or Young-Helmholtz, theory of vision. By this theory there are supposed to be three independent sets of photosensitive elements in the retina, one preponderantly sensitive to the short-wave part of the spectrum, and reporting violet or blue; a second, sensitive to the middle of the spectrum, and reporting green; and the third, sensitive to the long-wave part, and reporting red. By this theory the relative gain in sensitivity to blue experienced by the observer adapted to reddish-yellow light comes from the relatively low stimulation from the short-wave part of the spectrum produced by that kind of light, or alternatively, stimulation by reddish-yellow light desensitizes the red receptors and to a somewhat lesser extent, the green. The object colors perceived under reddish-yellow light are therefore the resultants of relatively increased stimulation from the long-wave portion of the spectrum combined with decreased sensitivity of the red and green receptors affected most by it.

Now a spectrally nonselective diffusing surface (10 to 40 per cent reflectance) usually appears closely gray to an observer adapted to the chromatic illuminant, even though the illuminant departs considerably from daylight quality (Judd, 1940; Helson and Michels, 1948). By the Young-Helmholtz theory the perception of gray corresponds to some fixed proportion (about equal) between the three responses (violet, green, red). This experimental fact may be invoked to yield by means of the theory at least an approximate prediction of the influence of chromatic adaptation by correcting the red, green, and violet responses for each viewed object by the same factor required to make the non-selective objects correspond to the fixed proportion of responses characteristic of gray for any given source of illumination.

3.1 Early Work. To show what experimental support this view has, we shall trace the development and test of it. Helmholtz (1860) early indicated the connection conceived by him between chromatic adaptation and the three independent mechanisms of Young's theory by saying (page 362): ". . . the nervous substance in question is less sensitive to new reacting light falling on it than the rest of the retina that was not previously stimulated. . . ." Following this enunciation of the principle, many observations were made of local color

changes due to a locally applied stimulus called the adapting light. The observer then looked at a uniform field called the reacting light and saw an after-image of the adapting light. The qualitative reports of the observer on the color of the after-image were then checked against the predictions of the theory. If the reacting light is gray, the color of the after-image is usually complementary to that of the adapting light, and this can easily be explained by the Young-Helmholtz theory. For example, Helmholtz (1860) says (page 367): "... Thus the after-image of red is blue-green; that of yellow is blue; that of green is pink-red, and vice versa... Thus an eye which has been acted on by yellow light, say, is thereafter in a condition in which the blue components of white light affect it more than yellow does. Accordingly, the effect of fatiguing the retina is not uniformly extended to every kind of stimulation, but chiefly to stimulation similar to the primary stimulation. This fact is explained very simply by Young's assumption of three different kinds of sensory nerves for the different colors. For since colored light does not stimulate these three kinds of nerves all to the same extent, different degrees of fatigue must also be the result of different degrees of stimulation. When the eye has been exposed to red, then the red-sensitive nerves are strongly stimulated and much fatigued; whereas the green-sensitive and violet-sensitive nerves are feebly stimulated and not much fatigued. If afterwards white light falls on the eye, the green-sensitive and violet-sensitive nerves will be relatively more affected by it than the red-sensitive nerves; and hence the impression of blue-green, which is complementary to red, will predominate in the sensation."

If we are going to predict quantitatively by the three-components theory the influence of chromatic adaptation, we must evaluate precisely the spectral sensitivity curves of the three components. It was already known in 1860 that in no part of the spectrum are two of these sensitivity curves equal to zero.

*3.2 **Persistence of the Optical Matches.*** To make a precise evaluation of the particular sensitivity curves applicable to prediction of the influence of chromatic adaptation required establishment of the central principle on which modern colorimetry is based, namely: that metameric color matches are not dependent on chromatic adaptation. The early work on this vital principle is well summarized by von Kries (1905) who names it *the persistence of the optical matches*, and states (page 209): "It is now established that for small and directly fixated fields optical matches show no change regardless of whether this retinal region has its adaptation changed by means of any light whatsoever. For example, a homogeneous yellow, and a yellow mixed from red and green, that under the usual conditions appear centrally equal, are seen after previous exposure to yellow light both more pale, and are seen after blue illumination both more saturated yellow, appear nevertheless always exactly equal to each other. Similarly the equality of a white undecomposed spectrally and a white mixed from two spectral complementaries is not destroyed if both, because of a previous chromatic illumination, appear strongly colored (in the complementary of the adapting light).

"The validity of this law has been tested recently in a systematic way by Mr. Bühler (1903), without a discrepancy ever having been found greater than the uncertainty of the observation. One may therefore take the independence of the optical matches, not, to be sure, for the adaptation of the whole visual mechanism, but rather for the central retinal region, or, stated theoretically, for the isolated portion of the visual mechanism functioning trichromatically.

"Hering (1893) has for a long time stated the independence of optical matches with adaptation with particular vigor and entirely generally. Later, however, Tschermak (1898) as has already been discussed above, in a study carried out under Hering's direction has reported a dependence of particular matches on adaptation, and has extended this statement (in my opinion wrongly) also to the center of the retina. Our law is therefore at many times (v. Kries and Nagel, 1896, 1900) and on different sides affirmed and denied, without the special conditions under which it holds having been determined."

More recently it has been shown by Wright (1934, 1936) that the optical matches also fail to persist if the fields are too bright. The breakdown occurs for fields yielding retinal illuminances in the range of 10,000 to 20,000 trolands. The special conditions under which this law supplying the basis for modern colorimetry holds are now considered to be those yielding vision by the retinal cones illuminated to less than 10,000 trolands. By virtue of this law, we can use the standard observer to compute the change in object-color when any source of known spectral-energy distribution (such as a fluorescent lamp) is substituted for any other known source of the same chromaticity.

*3.3 **The Coefficient Law.*** Before the precise evaluation of the spectral sensitivity curves of the three components presumed by the Young-Helmholtz theory could be carried out by colorimetric meth-

ods, another important principle had to be verified. This principle arose from the use of a retinal area near that pre-exposed to the adapting light as a control on the adaptive state of the former. The light, called the comparison light, falling on this control area was adjusted until it matched the reacting light. The objective difference between the reacting light and the comparison light color matching it served as a quantitative measure of the degree and kind of chromatic adaptation caused by the adapting light.

It was presumed by von Kries that the adaptive effect of the adapting light could be adequately expressed as a reduction of sensitivity by a constant fraction. In the words of von Kries (1905) it is reasonable (p. 211) "to assume that so far as the effect of an outer stimulus comes in question, the adaptation, whether of the visual mechanism in toto or of a particular part, makes itself effective as a greater or lesser sensitivity relative to each stimulus, and to be sure so that the result occurs always pretty much in accord with a product, aR, where R is the stimulus value, a, however, the disposition for this kind of stimulus. The simplification lies, as one sees, in the assumption that the modification which a stimulus-result undergoes through the existing sensitivity, allows itself to be represented for all chromaticities and photometric brightnesses simultaneously through the use of a coefficient. If this is the case, there exist several very simple laws, which also appear to be specially adapted for experimental test. Namely, it must be that, if L_1 on one retinal region causes the same result as L_2 on another, and similarly M_1, working on the first, causes the same effect as M_2 on the other, in every case also $L_1 + M_1$ must have here the same effect as $L_2 + M_2$ there. Especially must the equality of stimulus-results of two lights working on differently adapted retinal regions always remain fixed by proportional increase or decrease of the same. I wish to designate for short this assumption as the coefficient law. . . . A strict validity of the coefficient law can come into question only when the trichromatic apparatus functions in an isolated way, and the experimental test should be restricted on purpose to small directly fixated fields. . . .

"The extended studies of Wirth (1900-1903) show that the law can be considered as nearly valid for reacting lights that are not too weak. If this is the case, then we can say that each adaptation of the visual mechanism (more exactly of the color-engendering apparatus) compared with a definite, perhaps considered as standard, state is completely characterized if for three different lights (or light mixtures) is given the change in appearance they undergo because of the adaptation. Then, from this the change of any other light mixture whatsoever allows itself to be deduced."

3.4 Fundamental Colors. The coefficient law stated by von Kries and approximately substantiated by Wirth is an extension of Helmholtz' original conception that "the nervous substance in question is less sensitive to new reacting light falling on it than the rest of the retina that was not previously stimulated." The importance of this law was recognized by Wright (1934) who made some further checks on it in connection with his determination of the primary processes for his own eyes. Wright (1934) states (p. 63), "Now suppose R', G' and B' are hypothetical stimuli that produce responses along A, B, and C, . . . three independent sets of fibers to the brain. Then a reduction in sensitivity produced by light adaptation will, for a test colour that stimulates A alone produce an intensity depression of R' but no colour change; similarly if B or C are stimulated alone. Then if, in a given state of adaptation, R' were reduced to r' and G' to g', as each response is independent, $(R' + G')$ would be reduced to $(r' + g')$, $(2R' + G')$ would be reduced to $(2r' + g')$ and so on. In other words the geometry of the colour triangle holds equally well for the depressed eye as for the eye in its normal state. . . . Hence if the effect of a particular colour adaptation on the colours of the three instrument primaries R, G, B is known, then the effect on any colour in the colour triangle can be calculated.

"This deduction is also given by von Kries (1905), but it seemed desirable to check it experimentally and the results of one test are given below. . . . The agreement is remarkably close. Similar experiments have confirmed that result, although the margin of experimental error has usually been greater than here.

"The effect of varying the test colour is thus reduced to a matter of colorimetric additions and subtractions. If the intensity of the test colour is reduced, the recovery curves are reduced by the same amounts throughout; if the colour is changed, the change can be calculated provided the effect of the adaptation on three arbitrarily selected primaries is known. These conclusions must not be regarded as absolutely rigid; they appear to hold at least very approximately over a mean range of intensity.

"Determination of the Fundamental Response Curves: It has been mentioned above that if we could find a test colour that stimulated only one of the responses then no matter how the sensitivity

TABLE IV.—Fundamental Colors of the Young-Helmholtz Theory.

Method of Determination	Fundamental Color					
	Red		Green		Blue or Violet	
	x	y	x	y	x	y
Chromatic adaptation						
Wright	0.737	0.264	2.915	—1.768	0.134	0.022
Walters	.749	.253	14.39	—12.47	.....	.....
Dichromatic conjunctal points	.747	.253	1.00 to 1.20	0.00 to —.20	0.16 to .18	0.00

of the eye was depressed, no colour change could be evoked; for a colour change necessitates a change in the proportions of at least two of the responses and since only one is being stimulated, no qualitative change can be produced.

"Further if the positions in the colour triangle of these three fundamental stimuli were known, then the fundamental response or excitation curves could be computed by combination with the trichromatic mixture curves and the luminosity curve. Hence to determine these response curves it is only necessary to find those theoretical stimuli that, no matter how the sensitivity of the eye has been depressed, evoke sensations that are modified in intensity but not in colour.

"A direct investigation of the spectral radiations for this property can be made very easily. The patches in both the left and right eye can be illuminated with the same spectral radiation and the right eye can then be adapted with any coloured light. For a comprehensive test, red, green and blue adaptations should all be used. At the end of the adaptation the two monochromatic patches are again viewed and if no colour change has been induced in the right eye, it should be possible to obtain a match merely by reducing the intensity of the light in the left eye.

"If such a series of experiments is conducted, it is found that in two regions of the spectrum there are radiations in which only very small changes are induced. The first of these is in the extreme red, from 0.70 μ to the end of the spectrum. With this test colour, with any wavelength of adapting light, only an insignificant colour change is induced. . . . It has been shown above that once the effect on three primaries is known for a particular adaptation, the change produced on any given point in the colour triangle can be computed. It has now to be shown that the inverse process, the location of a point that has a given colour change, for our purposes zero change, is also possible."

By using this inverse process Wright determined for his own eye the color specifications of each of the three hypothetical stimuli required to stimulate separately the presumed independent processes by which the influence of adaptation is to be taken into account. These stimuli were specified in terms of the WDW coordinate system, but the specifications have been transformed to chromaticity coordinates (x, y) in the standard C.I.E. system by the transformation equations given by Judd (1944) and are given in Table IV.

In conformity to an early conclusion by Helmholtz, all three of these hypothetical stimuli correspond to colors more saturated than the spectrum colors. Thus, there is no part of the spectrum capable of stimulating one of the fundamental responses without at the same time stimulating at least one other of them. Extreme spectrum red comes the closest to doing this, fundamental red being only slightly beyond. The other two fundamentals are considerably super-spectral green and blue. Wright's results for his own eyes indicate definitely, moreover, that the third fundamental must be blue; it cannot be violet. He states (page 70), "On one point of previous dispute it is possible to come to a definite conclusion. It is quite certain that blue and not violet is the fundamental stimulus. It is only necessary to adapt the eye to a red radiation and observe the great change that is produced in a test colour at, say, 0.43 μ to prove that this radiation stimulates at least two responses."

Two of the colors (red and green) corresponding to the independent processes of the three-components theory were again determined by this method by Walters (1942) for his own eye. The chromaticity coordinates (x, y) of these colors in the standard C.I.E. system are also given in Table IV. The checks obtained for the coefficient law by Walters are not so good as those previously obtained by Wright, and this is ascribed to individual observer difference. Although the agreement between Walters' and Wright's determination of the fundamental red and green colors is fair, no determination of the third primary color was made by Walters, and he was uncertain whether it is blue or violet. He suggests that his results indicate that the three processes of the Young-Helmholtz theory are not entirely independent.

A considerably more reliable way to evaluate the

fundamental colors of the Young-Helmholtz theory would seem to be by means of the well-established facts of partial color blindness. There are three types of dichromatic vision, protanopia, deuteranopia, and tritanopia; and one of the great triumphs of the three-components theory is its simple, straightforward account of the colors confused by these types of dichromatic observers. The confusion colors for each type are found to lie along a family of straight lines on the chromaticity diagram intersecting closely at a single point. If the fundamental colors of the three-components theory are taken at the co-punctal points of protanopic, deuteranopic, and tritanopic vision, respectively, the three-components theory explains all three types precisely and in detail as being the result of a non-functioning of one of the three fundamental processes. Table IV shows for comparison the chromaticity coordinates (Judd, 1944) of the three co-punctal points. The agreement on the red primary is very good; but that for the other two primaries indicates the incomplete nature of the explanation already foreshadowed by the discovery that the coefficient law holds only approximately. It must be remembered, however, that these checks were obtained by colorimetric methods between a pre-exposed and a rested portion of the visual field. Although the defects in the coefficient law are easy to demonstrate by quantitative colorimetric methods, the central fact that the law holds approximately offers a promise of a simple approximate account of the changes in object-color perception due to chromatic adaptation of the whole visual field. These changes cannot be determined by methods of color matching; they must be estimated by relatively imprecise methods like the one used to obtain the present results.

3.5 Predictions Based on Three-components Theory. Many qualitative studies of chromatic adaptation of the whole visual field have been found to be satisfactorily summarized by the coefficient law though the authors of the accounts of these studies have not used that name for it, nor have they cited the previous work. Instead the ideas seem to have been developed independently from the general conception of the three-components theory. Thus Ives (1912) says: "Before leaving this topic a subjective element may be touched upon. After working for a time under a carbon lamp or other similar artificial light one ceases to notice that it is yellow. One apparently forms a new scale of color with unsaturated yellow as one's white. In this way compensation is introduced for the really enormous changes in color, which actually occur. Just how to represent this compensation is a matter probably yet to be determined. It might tentatively be assumed, however, that the three *sensations* are somehow re-weighted. . . . If now this same compensating process is applied to all the colors seen under this light, their distorted position is to some extent overcome. But not entirely, for the two different processes of color-change, one by change in spectral intensity distribution, the other by change in relative sensation intensities, never quite match. . . ."

Similarly, Noteboom (1935) describing a study of the adaptation produced by wearing chromatic goggles states: "In general, however, the lenses of goggles are held close to the eye so that the light from the surroundings, the room and so forth, is also filtered. Under these conditions the eye after a short time does not sense a white blotting paper as giving the impression of a green or a blue, or whatever the color of the lenses may be, but perceives it just as white as before putting on the goggles. There remains, therefore, only a reduction of brightness, the effect of the colored glass on perception being no different from that of a neutral gray glass on a white surface. This so-called adaptation of the eye to the color of the glasses takes place very quickly and completely for weakly colored glasses. With strongly colored glasses the eye takes a longer time, and also in extreme cases there is a remnant of perceived color on looking at a white surface. The change from daylight to artificial tungsten- or kerosene-lamp light without change in the white sensation is an example of this adaptation of the eye.

"In order to take account in the color triangle of this impression which the eye, or better to say, consciousness has, one must again equalize the color values belonging to the shifted white point, therefore to multiply them by factors easy to determine. In this way the color point again falls on the white point corresponding to the actual sensation.

"With these factors the values of the other color points are also to be multiplied, and in this way one obtains a representation of the sensations in terms of the unadapted eye. Whether this method corresponds to the observed facts is, to be sure, not known, but, on the one hand, the agreement with typical practical observations is quite good, and, on the other hand, there is scarcely a more plausible assumption to be made; above all, studies along this line are lacking."

It is evident that Noteboom was unfamiliar both with the early work summarized by von Kries (1905) and with the work of Wright (1934) which had appeared just a year before. Nevertheless he made use of exactly the ideas justified by that work.

The same thing is true of Ströble (1937) who writes: ". . . if one, for example, suddenly darkens a room illuminated by bright daylight and at the same time turns on the electric light, all objects during the first moment regardless of color (except very strongly saturated greens, blues and purples) appear with hues between yellow-green and red; but after a short time (of the order of a second) appear again in the original hues and saturations—though of course slightly shifted.

"The eye adjusts itself therefore to the changed illumination by the exact amount that this illumination happens to differ from the color of daylight. This adaptation of the eye does not show up in the color triangle, but it is possible to transform the chromaticity coordinates so that the point representing the illumination falls at the center of the color triangle. The question naturally arises whether such a transformation is physiologically justified. As was pointed out earlier, the fundamental sensation curves are experimentally determined, but the units of the fundamental sensations are arbitrarily adjusted so that the existence of a white color impression corresponds to equal amounts of the three fundamental sensations. If now this white color impression corresponds to another color, the units must again be chosen so that now this color falls at the center of the color triangle. . . .

"The computation of the above-described transformation is well established. The determination of the color coordinates of any given color in the new system consists, as is immediately obvious, merely in this that the known color coordinates in the old system be divided by the corresponding color coordinates of the light source in the old system, and that from the quotients the percentages be computed. . . ."

None of these authors states explicitly that the transformation to be valid must apply to the fundamental colors of the three-components theory, and to no other set of primary colors. Perhaps they tacitly assumed that the coordinate system they used was the fundamental system. Ströble used the König-Ives coordinate system (Ives, 1915); Noteboom, the system corresponding to the OSA excitation curves (Troland, 1922). Neither of these systems have primaries in good agreement with those specified in Table IV.

Attention was explicitly called by Evans (1943, 1948) to the importance of choice of coordinate system for this transformation. It is plain from Helmholtz' early accounts, as we have seen, that his conception applies only to the fundamental processes of the three-components theory; but this restriction has tended to be forgotten, or at least neglected, perhaps because no generally accepted determination of the colors corresponding to these processes has yet been made. Evans (1943) states (page 590), "Wright's work indicates that the relative responses of the eye receptors under a given set of conditions can be obtained by dividing the integrals of the stimulus with respect to each receptor, by the integral of the adapting luminant with respect to the same receptor. On careful consideration, however, it is apparent that there is only one possible set of sensitivity distributions for three primary receptors for which this result will hold. Wright (1934) determined such a set and referred to them as the 'fundamental' sensitivities of the eye. Walters (1942) has since redetermined them in the red and green regions and has thrown some doubt on Wright's values in the blue. . . ."

Evans (1943) further points out (page 600) that "because only one system can meet the requirements laid down, it is not likely that the I.C.I. primaries constitute such a system since they were chosen merely for convenience in computation." Nevertheless, our first theoretical computations were based on the C.I.E. (or I.C.I.) system because the C.I.E. tristimulus values for the Munsell samples used were already known (Kelly, Gibson, Nickerson, 1943; Granville, Nickerson, Foss, 1943) both for standard sources *A* and *C*, and it was hoped that this convenient and well-known international system of specifying colors could be used to give a valid first approximation of the influence of chromatic adaptation. Evans' conjecture proved, however, to be correct. The predictions based upon the C.I.E. primaries were found to be no more valid than the still simpler first approximation that object-color perception remains independent of changes in quality of the illumination (so-called color constancy).

3.6 Theory Tested. Our next theoretical computations were based upon the comparatively well-established dichromatic co-punctal chromaticities. The coordinate system based on these chromaticities (Table IV) as primaries may be defined by giving the connection between the tristimulus values, *R*, *G*, *V*, of any color in terms of the tristimulus values *X*, *Y*, *Z*, of that color in the C.I.E. system, which is closely (Judd, 1944) the following:

$$\begin{aligned} R &= 1.00Y \\ G &= -0.46X + 1.36Y + 0.10Z \\ V &= 1.00Z \end{aligned} \qquad (1)$$

For standard source *C*,

$$X_c = 0.980,\ Y_c = 1.000,\ Z_c = 1.181,$$

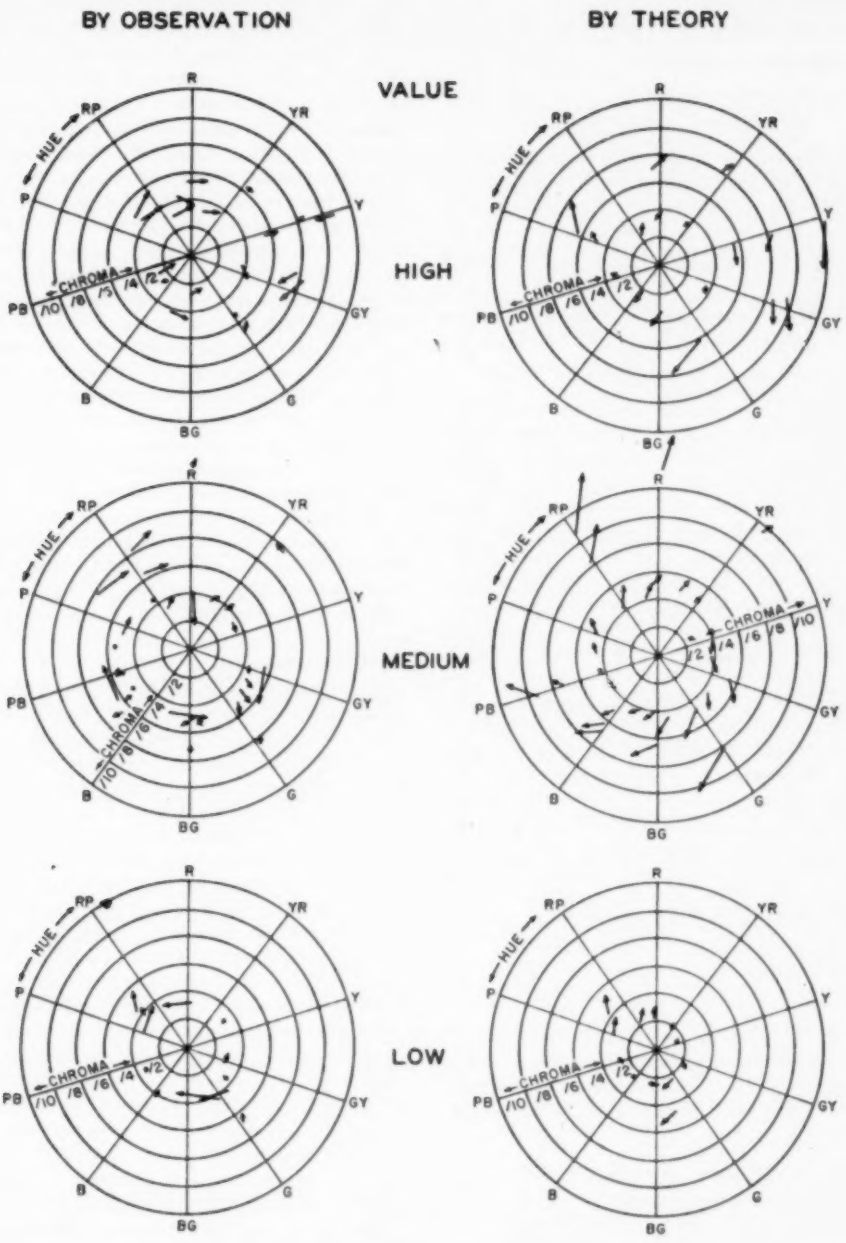

Figure 1. Changes in hue and saturation in passing from daylight (source *C*) to incandescent filament illumination (source *A*) according to observation and according to theory. Samples have been grouped according to high, medium and low reflectance and the observed data are for gray background.

and for source A:

$$X_a = 1.098,\ Y_a = 1.000,\ Z_a = 0.355.$$

From equation 1 we find:

$$R_c = 1.000,\ G_c = 1.027,\ V_c = 1.181$$

$$R_a = 1.000,\ G_a = 0.890,\ V_a = 0.355$$

To find the red, green and violet responses (R', G', V') of an observer adapted to incandescent-lamp light viewing an object under incandescent-lamp light, we have merely to write, in accord with the proposals of Ives, Wright, Noteboom, Ströble, and Evans:

$$R' = R(R_c/R_a) = R(1.000/1.000) = 1.000\,R$$
$$G' = G(G_c/G_a) = G(1.027/0.890) = 1.154\,G \quad (2)$$
$$V' = V(V_c/V_a) = V(1.181/0.355) = 3.327\,V$$

The coefficients, 1.154 and 3.327, indicate the sensitivities of the presumed green and violet mechanisms relative to that of the red caused by adaptation to standard source A; that is, adaptation to incandescent lamp light has made the green mechanism slightly more responsive and the violet mechanism more than three times as responsive relative to the red mechanism than was the case for adaptation to daylight. These changes in sensitivity are those required to account for the experimental fact that spectrally nonselective specimens are seen as gray by the observer adapted to standard source A. It remains to apply these same sensitivities to compute R', G', V' for each of the chips studied. The responses, R, G, V, for these chips are computed by equation (1) from the known tristimulus values (X, Y, Z) of the chip under source A; these responses apply to an observer adapted to source C. Then the responses, R', G', V', are computed from equation (2); these responses refer to an observer adapted to source A.

The next step is to find the corresponding Munsell renotation defined (Newhall, Nickerson, Judd, 1943) in terms of daylight reflectance, Y, and chromaticity coordinates, x, y, where:

$$x = X/(X + Y + Z);\ y = Y/(X + Y + Z) \quad (3)$$

if X', Y', Z' are the tristimulus values of the responses of the observer corrected for adaptation to source A, they may be written from equations (1) and (2) as:

$$X' = 1.154\,X - 0.458\,Y + 0.473\,Z$$
$$Y' = \qquad 1.000\,Y \qquad (4)$$
$$Z' = \qquad\qquad 3.327\,Z$$

The actual calculations for X', however, were made according to the equivalent expression:

$$X' = -2.509\,G + 2.954\,Y + 0.724\,Z \quad (4a)$$

the values of G having all been computed for the Munsell specimens previously from equation (1).

3.7 Theoretical Results Compared to Observations. From equations (3) and (4) the chromaticity coordinates, x' and y', corrected for chromatic adaptation to standard source A may be computed for each chip studied, and from Y', x' and y', may be read the Munsell renotation of the chips under source A corrected for adaptation by this theory. These are given in Table III, and the differences between the Munsell renotation of the chips seen under source C and the Munsell renotations of the chips seen under source A corrected for adaptation to that source are also given.

Fig. 1 shows by vectors in the polar-coordinate plots of hue and saturation the changes in the color perceptions of the chips caused by changing from standard source C to standard source A. It also shows for comparison the changes predicted by the theory. It is evident that there is general agreement between observation and theory, but in isolated cases the hue changes found are very different in amount and sometimes even in direction from those predicted. Furthermore Fig. 1 shows that the saturations perceived under source A should by this theory generally exceed those perceived under source C; but this is not borne out by the observations.

The discrepancies between the theoretical and observed saturations are statistically significant for all three backgrounds. The average difference between theoretical estimates and observers' estimates of saturation are 1.12 for white background, 0.67 for gray background, and 1.14 for black background with t-values of 5.71, 2.90, and 5.95 respectively, which are highly significant and therefore show significant departure of theory from observations. The differences between the theoretical and observed saturations are small for the most part, amounting to less than one step in the 0 to 10 scale of saturation employed by the observers. But because the predicted saturations tend to be greater than the observed saturations fairly consistently even this small difference proves to be statistically significant.

A similar statistical analysis of the differences between the theoretical and observed hues shows that the discrepancies are not statistically significant for any background. The average difference between theoretical and observed hues is 0.54 for white background, 0.58 for gray background, and 1.11 for black background with t-values of 1.24, 1.07, and 1.71 respectively. All three t-values lie between the 10 and 50 per cent confidence levels and therefore do not denote significant departure

of the theoretical from the observed hues. Hence we can conclude that the particular form of trichromatic theory tested here predicts adequately the hues perceived to belong to objects under source *A* from a knowledge of their C.I.E. chromaticity coordinates under this source.

In view of the approximate nature of the simple theory there is some question whether it is worthwhile to make computations based on other coordinate systems such as that indicated by Wright's work (see Table IV). Perhaps such calculations would improve the agreement between the observed and predicted saturation changes. One important result of the present study, however, is the establishment of the fact that people differ greatly with respect to chromatic adaptation. Further work* with other sources of illumination might yield a reliable basis for deciding between the various coordinate systems supposed to conform to the fundamental colors of the three-components theory. However, the goodness of fit of the theory to the data already obtained indicates that the assumptions underlying it are essentially correct for the conditions of this study, and that tables based on this theory and giving the changes predicted for various light sources of commercial interest might be of considerable practical value to the illuminating engineer.

Acknowledgments

We are grateful to the I.E.S. Research Fund for the financial support which has made this study possible, to Miss Dorothy Nickerson of the Production and Marketing Administration of the United States Department of Agriculture, who provided the Munsell standard papers, to Mr. Norman Macbeth of the Macbeth Corporation for supplying the daylight lamp sources used in this project; and to Brooklyn College for making available the laboratory space necessary for conducting this study.

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*Research is being continued at the University of Texas to include a study of colors under the cool white (4500K) fluorescent lamp.

Four New I.E.S. Reports Available

"I.E.S. Guide for Outdoor Illumination Tests," 8 pages. 25¢ per copy.

"The Functional Visual Activities in the Home," 11 pages. 25¢ per copy.

"Current Lighting Practice for Television Production," 7 pages. 15¢ per copy.

"Lighting of Central Station Properties," 20 pages. 50¢ per copy.

These reports may be obtained in single copies or in quantity, prices upon request, from Publications Office, Illuminating Engineering Society, 1860 Broadway, New York 23, N. Y.

Questions and Answers on light sources

The I.E.S. Committee on Light Sources, under the chairmanship of E. H. Raddin, has prepared this listing of answers to frequently-asked questions. Readers are invited by the Committee to submit similar questions of general interest on light sources, to be considered for publication from time to time. Questions may be sent in care of Society Headquarters.

What is the difference between a reflector lamp for lighting purposes and for infrared heating purposes?

The major difference is that the filament of the heat lamp operates at a lower temperature to give a longer life. For lighting applications a high luminous efficiency (high filament temperature) is desirable with a reasonable life. For heating applications the luminous efficiency has no importance; therefore, a long life can be provided by operating the filament at a lower temperature. Some reflector heat lamps have a red coating over the face of the bulb to reduce the brightness.

How does an infrared lamp heat an object?

The heat lamp radiates energy most of which is in the near infrared region. When the radiation is incident on an object some of the radiation is absorbed and converted into heat. The percentage of the incident radiation that is absorbed will depend on the infrared reflection factor of the surface, or of the material underneath if the surface coating happens to be transparent to infrared radiation. In general, dark colors absorb the radiation much better than light colors. The direct transfer of energy from the lamp to the object is the reason for the high speed of radiant heating.

What is the effect of preheat time on the life and discoloration of fluorescent lamps?

Both very short and very long preheat time tends to shorten lamp life and increase end-discoloration.

If the preheat time is very short, the cathodes will not have reached an adequate electron emitting temperature by the time the starter switch opens. As a result, the lamp may not start. If it does start, the cathode fall of potential will momentarily be too high, resulting in excessive erosion of emitting material by ion bombardment. This condition may not be too serious, particularly with recent cathodes. These modern cathodes do withstand this abusive treatment quite well as may be inferred from the rated life of instant start lamps (6000 hours), which, of course, have no preheat time at all.

Preheat currents and cathode temperatures are usually considerably in excess of operating currents and temperatures. The result is that if the preheat time is too long, excessive amounts of end-blackening in the form of anode spots will appear due to vaporization of barium from the electrodes. This loss of barium will also result in shorter lamp life.

For best results preheat lamps should start in one to three seconds after the switch is closed, depending on lamp size.

Which of the many available light sources do you recommend for color-matching purposes?

There cannot be one type of light source for all color-matching purposes since different spectral source qualities are desired for different color-matching conditions.[1] Possibly the most widely used color-matching source has been north skylight.[2] There are available color-matching luminaires which utilize scientifically selected light source — filter combinations to produce light of spectral distribution simulating north skylight closely enough for color-matching purposes.[3] For less discriminating color-matching tasks it is sometimes possible to use a single type of light source selected on the basis of spectral distribution.

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TELECAST

LIGHTING NEWS OF CURRENT INTEREST

I.E.S. Sponsoring Contest for "My Most Interesting Lighting Job"

Some Sections and Chapters have now completed their judging in the Society's contest for "My Most Interesting Lighting Installation." This worthwhile project is on a national basis this year, for the first time.

Winning entries of Section and Chapter contests will be presented at all of this year's Regional Conferences. Winners of the Regional Contests will be "finalists," competing for the final grand prize at the Chicago National Conference, as part of the Lighting Service Forum program.

These contests are a "natural" for the younger members of the Society. Cash awards plus national and local renown will accrue for many salesmen, contractors, distributors, manufacturers representatives, utility lighting specialists and others. Winners, and runners-up as well, will be considered for possible publication, with full credit, in ILLUMINATING ENGINEERING.

Prizes and rules of the local competitions may be set by the individual Sections and Chapters. For the Regional and National contests, rules have been drawn up by the Local Activities and Lighting Service Committees, copies of which have been sent to all I.E.S. groups. Regional Co-ordinator is Paul H. Hildebrand, Pennsylvania Power & Light Co., Allentown, Pa. National Contest Co-ordinator is Lee E. Tayler, Detroit Edison Co., Detroit, Michigan. Detailed copies of the rules and any further information with regard to the Contests, may be obtained from these men.

In addition to the prizes awarded by the Sections and Chapters, Regional Conference contests will award a first prize of $25.00, second prize of 15.00 plus honorable mention.

At the National Conference, the finalists will compete for:

First Prize	$100.00
Second Prize	50.00
Third Prize	25.00
Fourth Prize	15.00

Of even more importance than the money, however, is the opportunity for recognition in the presentation of one's work before a National Conference of I.E.S. and a by-lined article in ILLUMINATING ENGINEERING

Northern California Section Sponsors Twelve-Week Course

A twelve-week course in practical illumination for members of allied professions and businesses is currently underway under sponsorship of the Northern California Section of I.E.S. The course started March 17, in San Jose, March 18 in San Francisco and March 19 in Sacramento, with the Mother Lode Chapter cooperating in the latter city. The course followed immediately upon the close of the sixth annual Regional Technical Conference of the South Pacific Coast Region in San Francisco March 13 and 14.

In charge of the lighting course is John S. Walsh, chairman of the Section educational committee. Each lecturer will speak on successive evenings, Monday, Tuesday and Wednesday, in the three cities where the courses will be conducted.

Invitations have been mailed to architects, contractors, fixture designers, interior decorators, maintenance engineers, manufacturers' representatives and wholesalers' salesmen. Subjects to be presented include lighting fundamentals, light sources and control, design for offices, schools, stores and industry, and wiring and maintenance. Copies of I.E.S. recommended practices will be distributed.

H. H. Robison, general chairman of the Regional Technical Conference, detailed the program arranged under the direction of S. H. Hazleton, program chairman. Industrial and office lighting for increased production for defense was the conference theme. The first day was devoted to light sources and wiring design, concluding with "A Salute to Lighting Progress" presented by Alston Rodgers of the General Electric Company, Nela Park, Cleveland. On the second day design factors were featured. Sessions were held in the Hotel Sir Francis Drake.

Conference on Better Production Through Vision and Safety

A conference of special significance to industry was held at White Plains, N. Y., March 26, sponsored jointly by I.E.S., the New York University Center for Safety Education, the Greater New York Safety Council, and the Westchester Optometric Association. This was the full-day meeting attended by representatives from large and small industries, to show the benefits of safety programs and report the findings of the several groups studying safety factors.

One of the speakers at the Conference was I.E.S. Technical Director, C. L. Crouch, whose subject was "Planned Lighting for Production and Safety."

Other well-known specialists participating were:

Dr. Walter A. Cutter, Assistant Director, New York University Center for Safety Education. "Moving Ahead in Accident Prevention."

Mr. William J. Niederauer, Safety Director, Otis Elevator Company. "Vision in Industry."

Dr. Franklin M. Foote, Executive Director, National Society for the Prevention of Blindness. "The Wise Owl Eye Safety Program."

Summation.

Four I.E.S. Members To Address French Society

The Association Francaise des Eclairagistes has invited four prominent Members of this Society to address their Convention, scheduled April 26th to May 4 in Toulouse, France. American I.E.S. Members participating in the French I.E.S. program are: A. H. Manwaring; this Society's senior Vice-President; M. N. Waterman, Westinghouse Electric Corp.; C. A. Atherton, Westinghouse In-

ternational; and E. W. Commery, General Electric Co., Nela Park.

Mr. Manwaring will speak on the activities of the American I.E.S., and will also serve as this Society's official representative to the French Conference (see March I.E., p. 13A).

Mr. Waterman will address the group on "Developments in Mercury Lamps and Application in the U.S.A."

Mr. Atherton's subject will be "Organizations in the United States for expansion of the Lighting Market."

Mr. Commery will speak on "Improvement and Simplification of White Fluorescent Lamps in the United States."

It is some years since American specialists have participated in the activities of illumination groups in France. The growing interest in practical phases of lighting, developing from France's expanding electric power, is felt to be reflected in their interest in American techniques.

Optometrists Attend Forum on Visual Problems in Schools

A Forum on Visual Problems in Schools was held at Nela Park in mid-February, attended by 140 optometrists in Cleveland for a three-day convention. The group spent the day witnessing visual demonstrations of interest to optometrists and heard talks by S. K. Guth, in charge of Lighting Research, and Carl J. Allen, school lighting specialist.

Executive Committee Meets in New York

The Council Executive Committee held its bi-monthly meeting at Society Headquarters on March 13 for an all-day meeting of the Society's officers. Present were A. H. Manwaring and E. M. Strong, Vice-Presidents; R. F. Hartenstein, Treasurer; C. C. Keller, General Secretary; A. D. Hinckley, Executive Secretary; C. L. Crouch, Technical Director; Ruby Redford, Editor; C. E. Ellis, Advertising and Promotion Manager, and S. R. Williams.

Committee Appointments

A number of committee appointments were approved as follows

Sub-Committee on Technical Data Sheets, Section and Chapter Representatives: C. Harmon Bronner, L. V. Hadsell, E. F. McDonnell and Martin E. Staley.

Public Relations and Information — Section and Chapter Representatives: W. J. Flynn, J. Daniel Webster.

Tellers: Henry Chippindale, Jr., Chairman; Robert Decker, Walter Garrett, Winonah Murphy, Harold Peters, Warren Prediger, Matthew A. Veeck.

Color and Illumination: Johan C. Kronhout.

Elements of Signal Lighting: Glenn M. Kevern (replacing W. T. Harding).

Street and Highway Lighting—Sub-Committee on Principles of Street Lighting: Howard F. Ilgner, George W. Izant, Kirk M. Reid, Dana W. Rowten.

Television (Reception): S. K. Guth, co-chairman.

Representatives to Other Organizations

A.S.A. Sectional Committees:

Definitions of Electrical Terms—C 42: Harris Reinhardt.

Letter Symbols and Abbreviations for Science and Engineering—Z 10: Harris Reinhardt.

Drawing and Drafting Room Practice—Z 14: Harris Reinhardt.

Graphical Symbols and Abbreviations for Use on Drawings—Z 32: Harris Reinhardt.

Standardization of Optics—Z 58: Harris Reinhardt.

Handbook

Clayton E. Ellis, outlining the present position of the Handbook project, stated that the new edition is moving rapidly and will probably be sold out by October 1st or soon after.

Member Elections

On recommendation by the General Board of Examiners, 10 Members were elected to membership and approval made of 101 Associate Members and one Student Member. With other changes in membership, the present totals were reported as follows:

September 30, 1951		March 13, 1952
7166	Total Membership	7290
32	Members Emeritus	33*
42	Fellows	43
1709	Members	1741
5174	Associate Members	5314
209	Student Members	259

*Includes 10 Fellows of the Society.

Tennessee Valley Now a Section

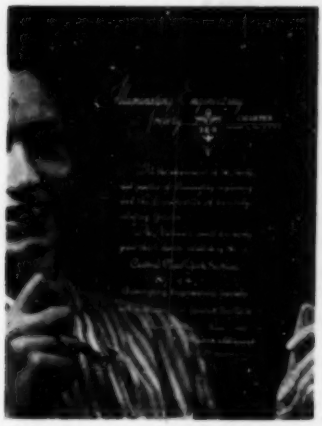
Action was taken on the petition of the Tennessee Valley Chapter, submitted through Cecil Pasley, Regional Vice-President, to grant Section status to this group.

A Section Charter was approved and will be presented at a meeting of the new Section in Nashville, Tenn.

ARIZONA Chapter entertains I.E.S. President S. G. Hibben. Shown during a luncheon meeting held in his honor in Phoenix, February 29, (l. to r.) Barney Hartley, Chairman of the new Chapter; Alston Rodgers a featured speaker at the meeting, and I.E.S. President Hibben.

Lighting Bibliography Available From Headquarters Office

A list of books, publications and periodicals, compiled by the I.E.S. Committee on Lighting Education, for handy use by those in the illumination field, is available without charge from the Technical Department of the I.E.S. headquarters office. Consisting of nine mimeographed sheets, this bibliography on light and lighting covers publications which made a definite contribution to the field of illumination, grouped according to the subject matter which they represent. These phases are (1) Lamps and Lighting, (2) Architecture and Lighting, (3) Physics of Light—Optics, (4) Color, (5) Light, Eyesight and Health—Related Psycho-Physiological References, (6) Trade Papers and Professional Journals in both English and foreign languages. Copies may be obtained on request to Technical Department, Illuminating Engineering Society, 1860 Broadway, New York 23, N. Y.



CHARTER of Central New York Section preserved for all time on photo sensitive glass.

Section Charter on Photo-Sensitive Glass

The Central New York Section is probably the only I.E.S. group whose Charter is preserved for all time on glass.

Corning Glass Works, who were hosts to the Charter meeting held last Fall at the New Glass Center, Corning, N. Y., reproduced the Charter in photo-sensitive glass after it had been left in their hands for framing.

The Charter is reproduced by the process of producing images in glass, similar to photography. Under exposure to ultraviolet light metallic particles melted with the glass, change their form on the exposed areas and become nuclei for crystal growth during a subsequent heating cycle. Thus by exposing through suitable patterns or negatives, pictures or designs of any shape may be produced three-dimensionally in the glass. With its unusual appearance and its complete resistance to effects of aging, the glass is useful for preserving records such as this Charter.

Oklahoma Chapter I.E.S. Makes Tulsa a City of Light

Through the activity of the new Oklahoma Chapter of I.E.S. in Tulsa, that city was transformed for six hours February 17, into a spectacular "City of Light." The occasion was the opening day of the 21st annual southwest Conference of Building Owners and Managers. The I.E.S. group persuaded building owners and managers to illuminate every building in downtown Tulsa as a

(Continued on page 9A)

LIGHTING CALENDAR

Society Events

April 20-22, 1952—Southern Regional Conference, Hermitage Hotel, Nashville, Tenn.

April 30 - May 2, 1952 — Canadian Regional Conference, Hotel General Brock, Niagara Falls.

May 5-6, 1952—Great Lakes Regional Conference, Statler Hotel, Cleveland, Ohio.

May 7, 1952—Meeting of I.E.S. Council Executive Committee, Cleveland, Ohio.

May 22-23, 1952—East Central Regional Conference, Webster Hall Hotel, Pittsburgh, Pa.

June 16, 1952 — Meeting of I.E.S. Council, Hotel Prescott, Swampscott, Mass.

June 19-20, 1952 — Northeastern Regional Conference, Hotel Preston, Swampscott, Mass.

July 10, 1952 — Meeting of I.E.S. Council Executive Committee.

September 8-13, 1952 — Illuminating Engineering Society, National Technical Conference, Edgewater Beach Hotel, Chicago, Ill.

Industry Events

March 22 - April 6, 1952—Chicago International Trade Fair, Navy Pier, Chicago, Ill.

March 24-28, 1952 — American Society Mechanical Engineers, Spring Meeting, Seattle, Wash.

March 26-28, 1952 — American Power Conference, Hotel Sherman, Chicago, Ill.

April 1-3, 1952 — Edison Electric Institute, Sales Conference, Chicago, Ill.

April 1-4, 1952 — Greater New York Safety Council, 22nd Annual Safety Convention & Exposition, Hotel Statler, New York City.

April 16-18, 1952—Electrical Manufacturers Representatives Club of New England, 11th Annual Electrical Trade Show, Exhibition Hall, Mechanics Building, Boston, Mass.

April 24-25, 1952—Industrial Electrical Exposition—Thirteenth annual equipment show sponsored by the Electrical Maintenance Engineers of Milwaukee, Public Service Building Auditorium, Milwaukee, Wis.

April 28-30, 1952—Canadian Electrical Distributors Association, General Brock Hotel, Niagara Falls, Ont.

April 28 - May 3, 1952 — Chamber of Commerce, Annual Meeting, Washington, D. C.

May 4-8, 1952—The Electrochemical Society, Inc., National Convention, Benjamin Franklin Hotel, Philadelphia, Pa.

May 5-7, 1952 — Engineering Institute of Canada, 1952 Annual Meeting, Hotel Vancouver, Vancouver, B. C.

May 5-9, 1952 — 33rd Annual National Restaurant Association, Convention & Exposition, Navy Pier, Chicago, Ill.

May 6-9, 1952 — Fourth International Lighting Exposition & Conference, Cleveland Municipal Auditorium, Cleveland, Ohio.

May 8-9, 1952 — Public Utilities Advertising Association, Annual Convention, Hotel Radison, Minneapolis, Minn.

May 12-13, 1952 — Electrical Contractors Association of Ontario, Annual General Meeting, General Brock Hotel, Niagara Falls, Ont.

June 2-5, 1952 — Edison Electric Institute, 20th Annual Convention, Cleveland, Ohio.

June 8-21, 1952 — International Organization for Standardization (ISO), General Assembly, Council and a Number of Technical Committees, Columbia University, New York, N. Y.

Week of June 9, 1952 — 44th Annual Convention, National Association of Electrical Distributors, Atlantic City, N. J.

June 9-13, 1952 — Third Annual Conference on Industrial Research, Columbia University, New York, N. Y.

June 23-27, 1952 — Summer General Meeting, American Institute of Electrical Engineers, Hotel Nicollet, Minneapolis, Minn.

Week of June 23, 1952—American Society for Testing Materials, 50th Anniversary Meeting, Hotels Statler and New Yorker, New York, N. Y.

June 30 - July 2, 1952—Canadian Electrical Association, Annual Convention, Banff Springs Hotel, Banff, Alta.

June 29 - July 7, 1952 — New York State Association of Electrical Contractors and Dealers, Inc., Saranac Inn, Saranac, N. Y.

August 19-22, 1952 — Pacific General Meeting, American Institute of Electrical Engineers, Phoenix, Ariz.

September 8-10, 1952—American Standards Association's Third National Standardization Conference, Museum of Science and Industry, Chicago, Ill.

September 8-11, 1952 — Institute of Traffic Engineers, Annual Meeting, Hotel Sherman, Chicago, Ill.

October 1-3, 1952—Canadian Electrical Manufacturers Association, 8th Annual Meeting, General Brock Hotel, Niagara Falls, Ontario.

October 7-9, 1952 — Pacific Coast Regional Restaurant Convention and Exposition, Biltmore Hotel, Los Angeles, Calif.

October 13-17, 1952—Fall General Meeting, American Institute of Electrical Engineers, New Orleans, La.

October 20-24, 1952 — 40th National Safety Congress & Exposition of the National Safety Council, Chicago, Ill.

November 10-13, 1952 — National Electrical Manufacturers Association, Haddon Hall Hotel, Atlantic City, N. J.

November 17-19, 1952 — 39th National Foreign Trade Convention, Waldorf-Astoria Hotel, New York, N. Y.

November 19, 1952 — 34th Annual Meeting, American Standards Association, Waldorf-Astoria Hotel, New York, N. Y.

January 19-23, 1953—Winter General Meeting, American Institute of Electrical Engineers, New York, N. Y.

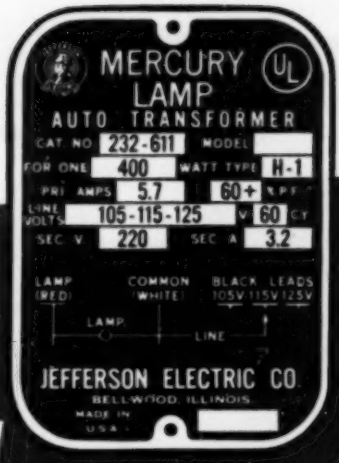
March 9-12, 1953—National Electrical Manufacturers Association, Edgewater Beach Hotel, Chicago, Ill.

Week of May 24, 1953—45th Annual Convention, National Association of Electrical Distributors, Stevens Hotel, Chicago, Ill.

June 29 - July 3, 1953 — Summer General Meeting, American Institute of Electrical Engineers, Atlantic City, N. J.

August 18-21, 1953 — Pacific General Meeting, American Institute of Electrical Engineers, Vancouver, B. C.

September 21-26, 1953 — 25th Jubilee Meeting, International Association of Electrical Inspectors, Edgewater Beach Hotel, Chicago, Ill.



HERE'S *THE NAMEPLATE TO LOOK FOR ON MERCURY LAMP TRANSFORMERS*

Beauty, quality and compact design are all combined in the new Jefferson Transformers. Sparkling new "Dura-Gray" finish eliminates eye-sore installations—blends with every surrounding—makes pole-top installations clean, neat, and streamlined as well as weatherproof.

The new revised line of Jefferson Mercury Lamp Transformers is designed and manufactured to give *peak* performance and *greatest* economy from your mercury lamp installations. No expense has been spared in giving you a transformer with *every feature vital to ideal lamp performance.*

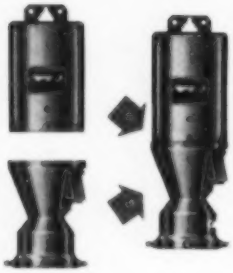
Jefferson Transformers are unmatched in performance and life because of these engineering advances:

- Three primary taps (not just two) are provided for a close match with line voltage. Long lamp life, full brilliance, positive starting, and maximum satisfaction result.
- Hot-dipped galvanized deep drawn steel cases give lifetime protection against severest weather. There are no seams to leak and be forced open by freezing. Scratches through paint *do not* cause rusting out. *All* Jefferson Outdoor Transformers are *first quality* and are in this rustproof case.
- Press-fit riveted core for positive electrical uniformity in manufacture.
- Leads cannot be pulled loose as they are securely stapled to the coil.
- Solidly welded bracket has keyhole mounting slot and two holes for locking in position. *One* man can install a Jefferson Transformer.
- The new Jefferson line includes transformers for operation of EH-1 and JH-1 at extremely low temperatures.

Get the most out of your mercury lamp installations by insisting on Jefferson. Over a third of a century of specializing in transformer design and manufacture is a *real* guarantee of top-flight performance.

Write for latest illustrated Bulletin 521-5.

JEFFERSON ELECTRIC COMPANY
Bellwood, Illinois



Only Jefferson has this Universal Adaptor!

All wall or post mounting Jefferson Transformers can be converted to pole-top models in minutes. Pole-top adaptor fits 2½" to 4" O.D. poles. Reserve stock cut to a minimum as one transformer fills most needs.

JEFFERSON TRANSFORMERS

(Continued from page 7A)

dramatic welcome to the building manager delegates.

All rooms on all floors of the downtown buildings were kept lighted for six hours. Since Tulsa lies on a plain with the business section in the center of a slight knoll (with many 30-story buildings closely grouped) the concentrated effect of glowing towers made a spectacular scene.

I.E.S. National Technical Conferences

September 8-13, 1952—Edgewater Beach Hotel, Chicago, Ill.

Week of September 14, 1953—Hotel Commodore, New York, N. Y.

Week of September 12, 1954—Chalfont-Haddon Hall, Atlantic City, N. J.

Winners of I.L.E. Gold Seal Award To Present Entries May 7

Twenty-three winning installations in the Gold Seal Award Competition, sponsored by the Fourth International Lighting Exposition of NEMA will be disclosed for the first time since the start of the contest, at a special Merit Award Session of the Exposition May 7. The contest is one feature of the International Lighting Exposition, to be held at the Cleveland Auditorium, Cleveland, Ohio, May 6-9 inclusive.

At the special Merit Award Session, entrants will point out the highlights of their Gold Seal Winning Installations while their entry is flashed on a 30-foot screen, according to G. T. Morrow, Chairman of the Merit Award Competition. This session is expected to draw record attendance.

In addition to the Gold Seal winners, some 250 other installations will receive Merit Award prizes and honorable mention.

The Competition attracted 480 outstanding lighting installations as entries. In the opinion of the judges, they were the finest installations ever submitted in a Merit Award Contest, according to Carl W. Zersen, Chairman of the Board of Judges. Serving as judges, in addition to Mr. Zersen, were Berlon C. Cooper, Eastern Editor of *Electrical Construction & Maintenance;* Prof. J. O. Kraehenbuehl, University of Illinois; B. J. Martin, *Electrified Industry;* and J. F. McCabe, Chicago Art Institute.

Entries were from 70 electrical contractors, 195 utility representatives, 44 electrical distributors, lighting specialists and salesmen, 70 architects and engineers and 30 owners and users. Entries fell under the following types of installations: 28 industrial lighting; 32 school lighting; 79 office lighting; 73 store lighting; and 75 miscellaneous installations.

Six Important Trends

The Judges reported six important trends in lighting practice, as indicated by their study of the 480 entries. These six trends are:

(1) New Lighting Techniques—Use of plastics and glass and combinations of light source, such as incandescent, fluorescent and mercury vapor. Lighting layout has been much improved and ceilings are being finished in lighter colors.

(2) Lighting System Designs are Better—They tie in architecturally. There are more geometric patterns from typical equipment shown. In many of the installations there are six and seven manufacturers represented showing that special equipment was chosen to solve particular problems.

(3) Better maintenance features shown—Provisions have been made for better, easier and quicker maintenance.

(4) Greater use of High Voltages—This is particularly illustrated in fluorescent and mercury vapor fixtures.

(5) Trend toward the use of 8-foot Slimlines.

(6) Entries were very definitely of a better quality of lighting. They are providing better visual environment.

Advance registration tickets to the Exposition are available from all exhibiting manufacturers or may be obtained by writing to the Public Relations Counsel, Fourth International Lighting Exposition, 326 West Madison St., Chicago 6, Illinois.

Advanced Lighting Applications Course in Boston

Six weekly classes in advanced lighting application were sponsored March 4 through April 8 by the New England Section of I.E.S.. The course was designed for lighting men with experience and background and was intended as a stimulant to those in the industry wishing to keep abreast of material and technical changes. Class instruction was supplemented by films, diagrams and descriptive literature. Actually, this was more than a refresher course. It was planned as a practical presentation of new information and up-to-date techniques. Subjects covered included:

Trends in Lighting Practice, by R. G. Slauer.

Acrylic Plastics for Illumination, by H. A. Williams.

Industrial Lighting—What's new in defense lighting, by L. S. Cooke.

Architectural Lighting—Unusual problems and how to solve them, by Edward A. Rambusch.

Light for Selling — Stores, Displays, etc. — Showmanship applied with finesse, by S. R. McCandless.

Light for Seeing—Offices, Schools, etc., An Old Subject with a new Approach, by H. R. Finney.

260 Potential Lighting Engineers Graduate This June

This year perhaps as never before, offers of employment are being showered on engineering and science college students who graduate this June. No exception to this situation, created by the defense emergency, are the 260 Student Members of the Society who are enrolled at colleges throughout the country. A number of leading manufacturers and electric utilities in the lighting field have long recognized the value of these engineering and science graduates and will be writing to the schools about job candidates. Sizable enrollments are concentrated in some sixteen of the nation's colleges and in most instances have been enrolled for special courses in illuminating engineering given by faculty members who are active in the Society. These include — Prof. C. L. Cottrell, Cornell University, Ithaca, N. Y.; Prof. John Kraehenbuehl, University of Illinois, Urbana, Ill.; Prof. L. C. Larson, University of Wisconsin, Madison, Wisc.; Prof. Russell C. Putnam, Case Institute of Technology, Cleveland, Ohio; Prof. R. W. Ahlstrom, Finlay Engineering College, Kansas City, Mo.; Prof. Warren D. Menke, Purdue University, West Lafayette, Indiana; Prof. Henry C. Simrall, Mississippi State College, State College, Miss.; Prof. W. D. Morris, Louisiana State University, Baton Rouge, La.; Prof. Abraham Abramowitz, City College of New York, New York, N. Y.; Prof. Dan M. Finch, University of California,

Berkeley, Calif.; Prof. Leland H. Brown, Stanford University, Palo Alto, Calif.; Dr. Charles Margach, Pacific University, Portland, Oregon; Prof. Delbert W. Shirley, Jr., Oregon State College, Corvallis, Oregon; Dean Arthur B. Gallion, University of Southern California, Los Angeles, Calif.; Dr. M. E. Broom, Southern College of Optometry, Memphis, Tenn.; Prof. P. A. Cartwright, University of Minnesota, Minneapolis, Minn.

Handbook Subject of Study Club Meeting

The New England Section Study Club had an idea worth copying by other Sections, in their meeting February 20 devoted to the study of the new I.E.S. Lighting Handbook. Revisions from the first book were specially stressed.

William Kennedy of Sylvania Electric Products, Salem, Mass., led the discussion.

The Study Club meeting was followed by the regular Section meeting at which a discussion of "Application of Article 410 (Lighting Fixtures, etc.) of the National Electrical Code" was presented by John W. King, consulting electrical engineer for architects.

Clinic Series Feature Color and Lighting

As part of their series of lighting clinics, three of which were successfully completed this past winter, the Chicago Section conducted a Color Clinic April 4, in cooperation with the Chicago Lighting Institute. Following the same pattern as previous meetings, authoritative speakers were featured, capsuling a one-day course in color and its relation to illumination.

Chairman of the Clinic was Walter C. Granville, well-known color expert for the Container Corporation of America. Subjects featured were:

Interrelation of the Various Field of Color, by Carl E. Foss.
Color Vision, by Dr. Jozef Cohen.
Tools for Solving Color Problems — Present and Future, by Carl E. Foss.
The Light Side of Color, by Carl F. Jensen.
Color Planning for Interiors, by Lucille Knoche.
Color Conditioning of Office Equipment, by George Harker.
Question and Discussion Period.
Closing Remarks, by Charles N. Laupp.

The regular I.E.S. meeting, held jointly with the Chicago Section Residence Lighting Forum, followed the Clinic sessions, as an evening continuation of the program. Color was also the subject of this meeting, featuring Louis Chiskin, Director of the Color Research Institute of America who talked on "Color Tuning Your Home."

I.E.S. Regional Conferences, 1952

Southwestern	Hotel Tulsa Tulsa, Okla.	April 6-8
Southern	Hermitage Hotel Nashville, Tenn.	April 20-22
Canadian	General Brock Hotel Niagara Falls, Ont.	April 30 - May 2
Great Lakes	Statler Hotel Cleveland, Ohio	May 5-6
East Central	Webster Hall Hotel Pittsburgh, Pa.	May 22-23
Northeastern	Hotel Preston Swampscott, Mass.	June 19-20

Advanced Lighting Course Held in Pittsburgh

The Pittsburgh Section of I.E.S. has just completed a series of six weekly lectures conducted as an Advanced Course in Lighting, sponsored jointly with the Electric League of Western Pennsylvania.

Held each Monday evening March 3 through April 7, the subjects covered were :

Revised Coefficients of Utilization—What They Mean, by J. R. Jones.
Visibility Meter and Its Use and Value—Classroom Practice, by Cory Crysler.
"Illumineering" For an Optimum Luminous Environment, by H. L. Logan.
Operation of Electric Discharge Lamps Under Adverse Weather Conditions, by Al Paulus.
Comparison of School Lighting Systems, by Lucian Kight.
Infrared, Theory, Sources—Spectral Analysis, Applications, by Ira J. Barber.

Technical Committee To Meet With Indiana Chapter

The joint conference of the Aviation Lighting Committee and the Indiana Chapter, scheduled May 15 and 16 in Indianapolis, will mark the first time in Society affairs that a local Chapter and a Technical Committee have combined to present a conference of major importance. The two-day meeting has been arranged under the sponsorship of the C.A.A. Technical Development and Evaluation Center of Indianapolis.

The Spring Technical Conference of the Aviation Lighting Committee will feature a number of papers of interest to I.E.S. members.

As a side note of interest in connection with the meeting, time trials for the famous Indianapolis Speedway Classic will be in progress at the time, and visiting delegates may work this into their schedule.

BOOKS AND PAMPHLETS

*Books whose reviews are marked * are available for inspection at Headquarters Office, Technical Dept.*

***Neon Signs and Cold Cathode Tubing**, by Samuel C. Miller, published 1952 by McGraw-Hill Book Co., Inc., New York; 406 6 x 9 inch pages, 151 illustrations, 29 tables; price $6.00.

This second edition of *Neon Signs* (by Miller and Fink, published in 1936) presents a complete, step-by-step discussion of luminous tubing manufacture, installation and maintenance. The author's intent was "to be clear, complete, and practical-minded in presenting information useful to the experienced sign manufacturer as well as to the newcomer." This up-to-date manual of luminous and fluorescent tubing manufacture and application contains a wealth of information which should be of interest to all connected with this rapidly expanding industry.

The first two-thirds of the volume deal with fundamentals of luminous tube manufacture (theory, materials, electrical equipment, and types of signs) and shop practice; the third section includes fluorescent lighting manufacture, both hot and cold cathode, and illumination design data to enable a manufacturer to design lighting installations; appendices give the Underwriters' Laboratories' Requirements for Electric Signs and American Standard Building Code Requirements for Signs and Outdoor Display Structures.

***Electric Lighting**, by C. E. Gimson, published 1951 by the Cleaver-Hume Press, Ltd., 42a South Audley Street, Lodon; 224 4½ x 7¼ inch pages, 79 illustrations; price 9s 6d (approx. $1.50).

(Continued on page 14A)

Art Museum

Chooses Lighting Artistry by LITECONTROL

JOB: Art Museum of New Britain Institute, Stanley Wing, New Britain, Conn.
ARCHITECT: Delbert K. Perry & Associate, John Perry, New Britain, Conn.
ELECTRICAL CONTRACTOR: Peterson Electric Co., New Britain, Conn.
FIXTURES: 30 Special No. F74 4-lamp fixtures.
4 Special 4-lamp corner mitred fixtures.
LAMPS: Standard warm white fluorescent.
AREA: 32' x 60' x 12' ceiling height — 1,920 square feet.
WATTS: 6,500.
WATTS PER SQUARE FOOT: 3.3.
AVERAGE INTENSITY ON PAINTINGS, vertical plane (outside row of lamps only) 20 footcandles in service. (With all lamps on) 32 footcandles in service.

Here paints the magic brush of light . . . custom-tailored by LITECONTROL . . . by the ingenious modification of *standard Litecontrol fixtures.*

But because they are crafted by lighting artisans . . . and made in many styles and designs . . . LITECONTROL fixtures provide installations which are "standard" in price only, definitely *custom* in appearance and performance.

Problem here was to enable paintings on wall to be featured or, when desired, to permit featuring of floor displays (see small photo). *Planned Lighting by Litecontrol* provided fixtures with outside lamps operating independently of inside lamps, with light shielded by a vertical baffle. Thus, the outside row alone evenly illuminates the paintings around the walls, or the inside row alone can be used to highlight center displays. Note how the fixture row follows the room contour, even at the mitred walls, for evenness of illumination.

On your next lighting problem, call in LITECONTROL — *and save.*

LITECONTROL *Fixtures*

KEEP UPKEEP DOWN

See You at Booth 102, Lighting Exposition

LITECONTROL CORPORATION, 36 Pleasant Street, Watertown 72, Massachusetts

DESIGNERS, ENGINEERS AND MANUFACTURERS OF FLUORESCENT LIGHTING EQUIPMENT DISTRIBUTED ONLY THROUGH ACCREDITED WHOLESALERS

by all LIGHTING Standards . . . When compared with the most approved standards in the science of illumination, "Magna-Flo" systems excel: in *high lighting efficiency*, because these units are specifically designed for maximum utilization of the highly efficient T12 Slimline Lamp; in *high light output*, providing high footcandle readings on vertical surfaces and horizontal levels; in *proper brightness balance*, to provide maximum visual comfort and seeing efficiency; in *elimination of direct glare*, to reduce eye fatigue and interference with vision.

BENJAMIN "Magna-Flo" Excels!

Compare Benjamin "Magna-Flo" Industrial Lighting Systems with *all* established quality standards. You'll easily see why "Magna-Flo" units excel *all* ways! The "Magna-Flo" line is SO COMPLETE that over 300 combinations are possible from just 4 basic reflectors and 3 channels. This completeness makes possible TASK-MATCHED installations for the proper lighting of practically all types of industrial seeing tasks. In addition, "Magna-Flo" excels:

by all ELECTRICAL Standards . . . In "Magna-Flo" units you get equipment that meets the maximum established electrical standards to assure simplified installation, high efficiency and dependable operation. Top-of-channel knockouts provide handy line-wire entrances. Channel caps are easily fastened to the channel by two screws. For maximum efficiency and continuously-cool operation only high-power factor "ETL"-approved ballasts are standard equipment on "Magna-Flo" lighting units.

by all CONSTRUCTIONAL Standards . . . You'll find "Magna-Flo" excels in all ways to assure longer life and quicker, simplified maintenance. Reflecting surfaces are genuine "Life-Time" Porcelain Enamel, which does not discolor, scratch or become dull. Year after year, original light-reflecting efficiency can be sustained by simple soap-and-water cleaning. Further, "Magna-Flo" *excels because* ONLY "Magna-Flo" has "Springlox". This all-metal lampholder speeds up re-lamping, improves lighting equipment maintenance.

Write for Bulletin AD-5705, Benjamin Electric Mfg. Co., Dept. I. Des Plaines, Ill.

(Continued from page 10A)

This little book is written in layman's language for "everyone who has a personal lighting problem in business, industry or the home." Almost all the application information and problems are, however, based upon current British lighting practice which, for economic reasons, is limited to levels of illumination far below those in use and recommended in this country today.

Chapter headings are as follows: Good and Bad Lighting, Light and Our Eyes, Measurement of Light, Filament and Gas Discharge Lamps (with data on bases, mechanical and radiation characteristics, and circuits for *British* lamps), Lamp Fittings, Indoor Lighting Systems (design information), Indoor Applications (mostly examples of supplementary lighting, well presented), Outdoor Lighting Systems (equipment characteristics and instructions for making layouts), Outdoor Applications (mostly qualitative treatments of yards and private roads with layouts for a few recreational areas), Lighting for Advertisement and Display. The appendices give reflection and transmission factors, British I.E.S. recommended values of illumination, tables of data for British lamps, and room indices and coefficients of utilization. There are also seven pages of questions and answers on the material covered by the book.

Principles of Lighting, by W. R. Stevens, published 1952 by Constable and Company, Ltd., 10 Orange Street, London; 492 5½ x 8½ inch pages, 200 illustrations; price 35s. (approx. $5).

This volume contains a wealth of fundamental and design information. Because the author delves deeply into the technical (more so than many American lighting engineers) this will be an excellent reference book, although perhaps too "meaty" for use as a text for introductory illumination courses. The author has drawn text and illustrations from lighting practice and literature from the European continent and this country as well as Great Britain.

Topics treated include light and units of measurement, the process of seeing, color, photometry, artificial light sources (beginning with an excellent four-page treatment of gas lighting, still used in many places today but almost completely ignored in recent literature), luminaire design (optical systems and mechanical and thermal considerations), bases of installation design, daylighting, and applications: industry, stores, offices, schools, homes, roadways (a considerable amount of British material not generally available in the U. S. and treating also of automobile headlighting and the illumination of traffic signs), motion picture and television studios, stage lighting, airports and seadromes, decorative lighting, floodlighting, sports, museums, photographic applications, plant growth and even slide and motion picture projectors. Appendices give tables of zonal constants, room indices and coefficients of utilization for British equipment, Harrison-Meaker glare ratings, a brief treatment of the interflection method of determining brightness distribution, equations for the illumination from sources of various geometric configurations, conversion factors for brightness and illumination units, brightness of typical light sources, a glossary, and graphs showing the effect of voltage variations on the operating characteristics of British incandescent, mercury, sodium and fluorescent lamps. Each chapter contains a comprehensive some American publications. At the conclusion of the book is a list of the foremost English-language books on lighting.

Airport lighting equipment selection and electrical requirements are covered in an 18-page booklet now available from the Westinghouse Electric Corp., Box 2099, Pittsburgh 30, Pa.

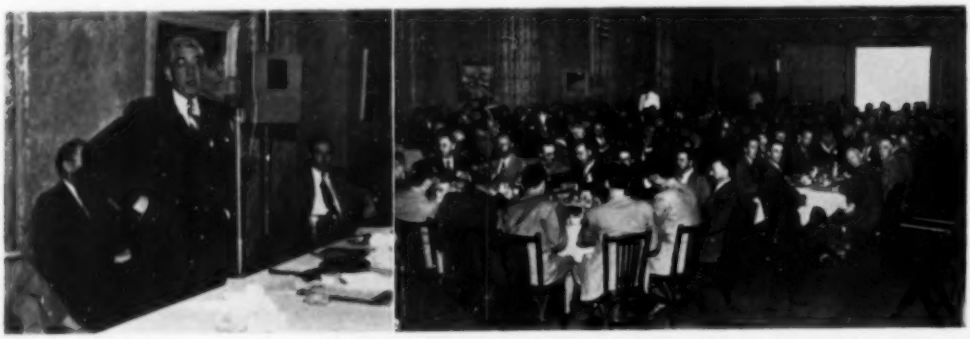
Because CAA specifications of electrical equipment vary with the class of airport, this booklet, B-5428, presents first several typical wiring diagrams for runways and taxiways. In addition to a general description of the product, information is supplied on where the equipment may be best applied and what accessory apparatus is essential to its operation.

The Why, When and How of Modern Lighting Maintenance is a 12-page bulletin available from the Lighting Division of Sylvania Electric Products Inc., 60 Boston St., Salem, Mass. An 8-step program of planned fluorescent lighting maintenance is presented and the advantages of planned group replacement of lamps is stressed.

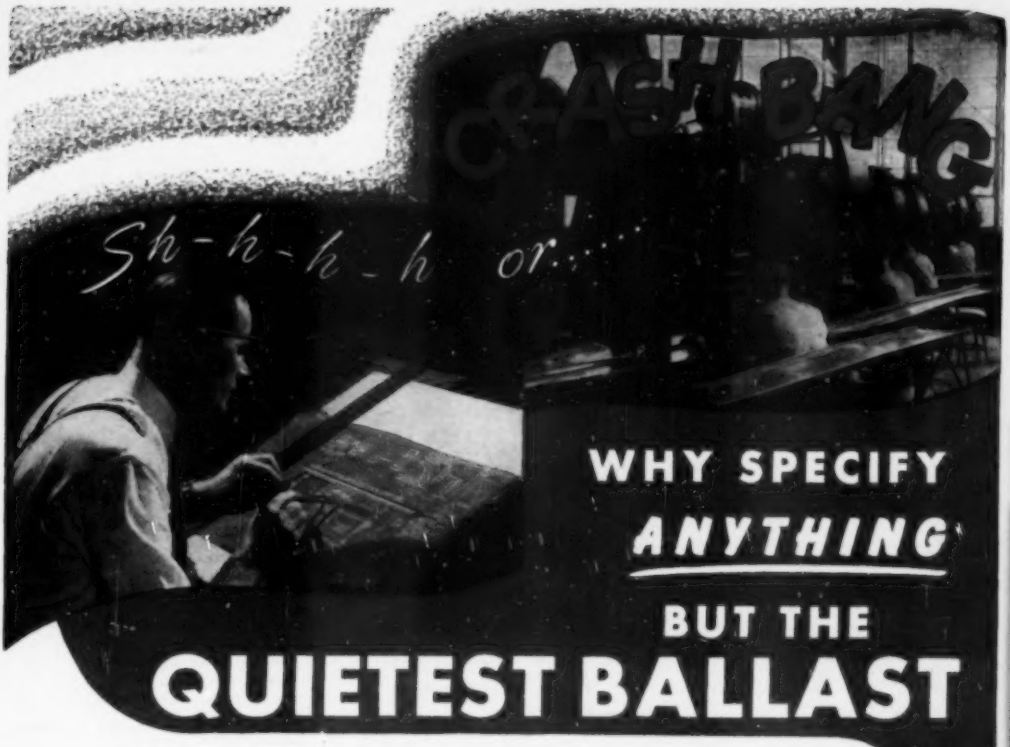
Electrical data book for architects and engineers has now been revised by Westinghouse Electric Corp. to keep it up to date with the construction business. The 330-page booklet, B-2161-E includes information on new equipment and methods of using this equipment and an entire new section on power distribution. It is available from the district offices of Westinghouse.

Electric Vitamins for the Outlet Hungry Home, a 12-page, pocket size reprint, first published in 1949, has been reprinted again and is available from National Electric Products Corp., Pittsburgh 30, Pa.

(Continued on page 16A)



THREE HUNDRED members of the Southern California Section of I.E.S. and A.I.E.E. joined for a special dinner meeting March 5, honoring I.E.S. President S. G. Hibben. Speakers were Mr. Hibben, shown at left, who addressed the group on "The State of the Nation's Lighting" and Alston Rodgers, Nela Park, who gave a demonstration of "Lighting Progress of the past year.



WHY SPECIFY *ANYTHING* BUT THE QUIETEST BALLAST

For ALL your FLUORESCENT INSTALLATIONS

Every Advance Ballast is made to operate at the minimum noise level. You can specify Advance with confidence for ***EVERY*** job.

CERTIFIED

UL E·T·L

ADVANCE TRANSFORMER CO.

The Best Ballast Buy

CABLE ADDRESS: ADTRANS

1122 W. CATALPA AVE., CHICAGO 40, ILL., U.S.A.

(Continued from page 14A)

NEW MEMBERS

At the meeting of the Council Executive Committee held in New York City on March 13, 1952, the following were elected to membership:

ALAMO CHAPTER

Member:

Vernor, T. A., Jr., 304 Green Ave., Taft, Tex.

Associate Members:

Mayhan, V. T., City of San Antonio, San Antonio, Tex.

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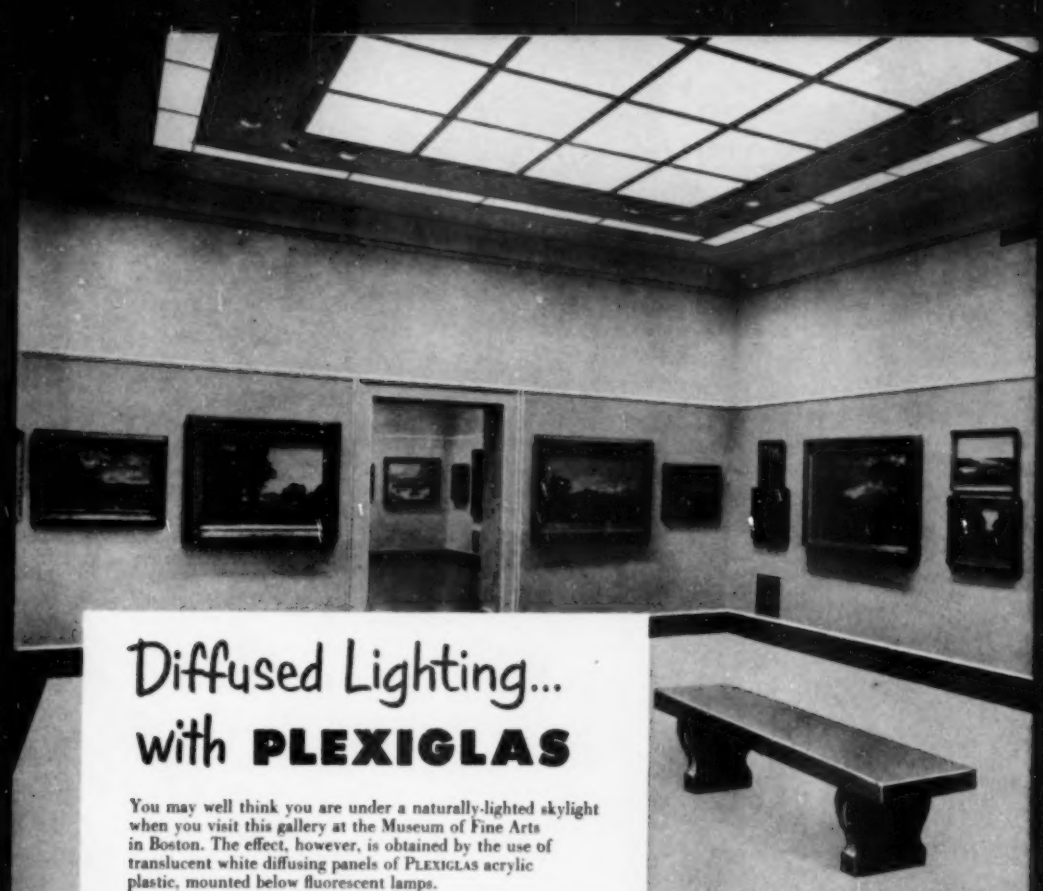
(Continued on page 32A)



Diffused Lighting... with PLEXIGLAS

You may well think you are under a naturally-lighted skylight when you visit this gallery at the Museum of Fine Arts in Boston. The effect, however, is obtained by the use of translucent white diffusing panels of PLEXIGLAS acrylic plastic, mounted below fluorescent lamps.

PLEXIGLAS luminous ceilings provide high quality lighting in eight new exhibition rooms at the Museum. The totally *diffused* illumination is free of shadows and reflected glare. The effect of daylight, the most desirable condition for human vision, is achieved and the disadvantages of depending upon natural light, with its constantly shifting values, are eliminated.

The even spread of artificial light across the PLEXIGLAS surfaces and the absence of visible lighting fixtures make the luminous ceilings architecturally appealing. Higher light intensity and full color values for the paintings are supplied by directional louvers and recessed spotlights.

PLEXIGLAS luminous ceilings satisfy the requirements of architects and lighting engineers for low brightness ratios, high illumination levels, excellent diffusion, and fixture-free appearance. In addition, the lightweight yet strong diffusers are removed easily and safely for cleaning and for access to the lighting source, resulting in a sustained high level of lighting performance.

If you have a lighting problem, investigate "daylighting" with a PLEXIGLAS luminous ceiling. We will be glad to send you technical details about the installation shown above. Write for them.

The Rohm & Haas exhibit at the Fourth International Lighting Exposition and Conference, May 6-9, Public Auditorium, Cleveland, Ohio, will be in Booth 153.

Special Galleries, Museum of Fine Arts, Boston, Massachusetts. Architects: Leland and Larsen, Boston. Illuminating engineers: Thompson Engineering Company, Boston. Photograph courtesy of General Electric Company.

CHEMICALS FOR INDUSTRY

ROHM & HAAS COMPANY

WASHINGTON SQUARE, PHILADELPHIA 5, PA.

Representatives in principal foreign countries

PLEXIGLAS is a trademark, Reg. U.S. Pat. Off. and other principal countries in the Western Hemisphere.

Canadian Distributor: Crystal Glass & Plastics, Ltd., 130 Queen's Quay at Jarvis Street, Toronto, Ontario, Canada.

A man's work is his Cathedral

Edwin F. Guth, Sr., has given fifty years of his life to his work with almost religious devotion. His efforts have been rewarded.

His company, now celebrating its Golden Anniversary, is recognized as one of the leaders in the lighting industry. He has achieved fame for his contributions to the betterment of lighting. We at GUTH pause to honor this man who has shaped the past and future of our company.

Thanks, E. F. Guth, Sr. And thanks to all of you who have been so wonderful to us during this past half-century.

GUTH'S GOLDEN YEAR..

19 Guth 52

...leaders in lighting since 1902

THE EDWIN F. GUTH CO. / ST. LOUIS 3, MO.

"...his deeds have made us what we are today"

In devoting a half-century to his work, Edwin F. Guth, Sr., has built a record of accomplishments that stands as a monument to his untiring spirit:

Founded our company April 22, 1902.

Invented over 150 patented lighting devices.

Designed the world-famous BRASCOLITE.

Introduced the first "Packaged" Lighting Fixtures for distribution through wholesalers.

Designed and manufactured cast bronze lighting equipment for many state capitols and other public buildings all over the world.

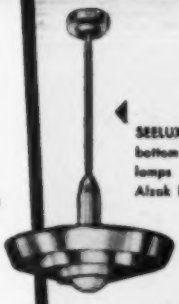
Produced the finest reflector finishes as they were developed — Alzak Aluminum, Porcelain Enamel, 300° White, and Electroplated Finishes.

Created the famous GUTHFAN — the first improved fan over a 30-year period.

Designed and manufactured lighting equipment through all stages of lighting development — Gas Fixtures, Gas Mantles, Combination Gas & Electric, Carbon, Gem, Tantalum, Tungsten, Mercury, Fluorescent, and Germicidal — from 1902 to the present.

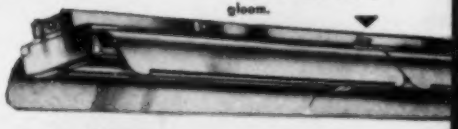
Honored by the National Association of Manufacturers which named him, "A Modern Pioneer on the Frontier of American Industry".

THE EDWIN F. GUTH CO. / ST. LOUIS 3, MO.

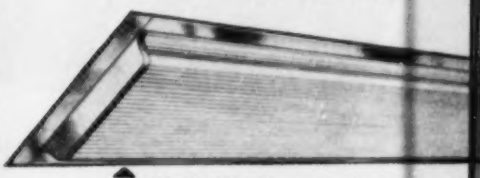


SEELUX* 3-ring, open-bottom for silver bowl lamps with heatproof Alzak louvres.

WYTE-LINER the new idea for factory lighting: white inside and out. Results: lessens contrasts — lifts ceiling gloom.

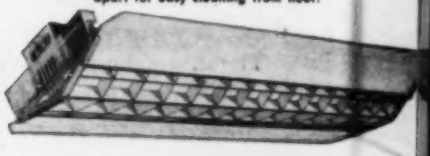


GUTHLITE* swings down for easy maintenance. 43% uplight, 57% downlight.



LITE-BLOX TROFFER comprehensive line — ribbons of light — super constructed.

ARISTOLITE* hinged glass panels swing apart for easy cleaning from floor.



HIGH-BAY

DOME

GLASS ALZAK

INDUSTRIAL INCANDESCENT reflectors for better light control at the working plane.

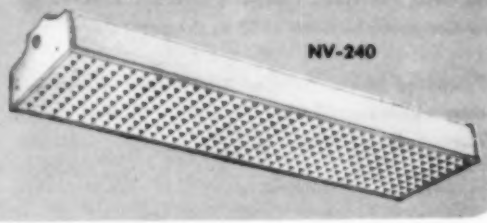
* ® and Patents Pending

. . . invest in EFFICIENCY
get Beauty and Economy, too!

Efficiency of highest order, to meet the most rigid standards of performance . . . *economy* in installation cost and operational expense, to stay within modest budgets . . . *beauty* of styling and material, to please the eye . . . all these are yours in Leader's NEW VARSITY fixtures. Don't be satisfied with less! The strong downward distribution of light, combined with proper shielding, makes these fixtures the ideal choice for classrooms, offices, libraries . . . wherever "close seeing" is a constant requirement.

SPECIFICATIONS

Channel and end caps of steel, finished in white baked enamel. Translucent plastic side panels and free-swinging plastic louver which provides 40° x 40° shielding. For two, three or four 40-watt lamps, or Slimline lamps in 72" or 96" length. Precision engineered throughout for superb efficiency.



Sold and installed by better electrical wholesalers and contractors

Leader *America's No. 1 Lighting Equipment Manufacturer*

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one thousand and one reasons why
over 10,000 will attend . . .
"The facts and data that I pick up about the latest developments and advances in lighting equipment are invaluable to me in selling my lighting lines."
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"As an electrical contractor, the new ideas I pick up on PLANNED LIGHTING help me in my business."
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"I think every architect will find the new techniques and equipment, displayed and described at the Exposition, a big help in planning lighting."
"I am particularly interested in seeing the winning Case Studies in the Merit Award Competition."

4th International LIGHTING EXPOSITION and conference

See for Yourself How Lighting Knowledge Can Help You ...Your Industry...and Advance America's Welfare

Since the Third International Lighting Exposition, in March of 1949, much has happened in the lighting industry. You can find out what has happened and what's ahead in lighting at the Fourth International Lighting Exposition. Here, at one great Exposition and Conference, you will see the latest in the world of lighting... you will see and hear how to plan and use the latest lighting knowledge in your work. See the latest advances and developments in Planned Lighting for all kinds of businesses, industries, schools, theaters, service stations, airports, play areas, etc. Hear and meet leading manufacturers and authorities on lighting to learn what is ahead in the science of illumination. You can get all of this in Cleveland in four, big, action-packed days.

The program committee has lined-up an impressive list of speakers—all leading authorities on their own phase of the lighting industry. Plan now to attend—send the coupon below for your Free Advance Registration. Avoid waiting in line.

...See the *Merit Award Winners in a Bigger than Ever Court of Honor*

As in previous International Lighting Expositions, one of the highlights of the show will be the awarding of the Merit Award Certificates and the Gold Seal Merit Award Certificates to the winners in the big 1952 Merit Award Competition. All the winners and many other Case Studies will be put on display in the spacious Court of Honor for you to study.

There will be more and bigger exhibits than ever before by outstanding lighting equipment manufacturers and manufacturers of allied products. You will find the greatest array ever gathered under one roof of industrial and commercial lighting fixtures for incandescent and fluorescent lamps . . . plastic, glass, paint and allied products that are of definite interest to lighting people.

CLEVELAND MAY 6-9, 1952

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APPLICATION FOR FREE ADVANCE REGISTRATION

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Without obligation, I wish to apply for free Advance Registration at the FOURTH INTERNATIONAL LIGHTING EXPOSITION and CONFERENCE.

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THE FOURTH INTERNATIONAL LIGHTING EXPOSITION is sponsored as a public service by the Industrial and Commercial Lighting Equipment Section of the NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION.

GUIDES YOU SAFELY

Most streets are ten times as dangerous at night as in the daytime. This is proven by accident statistics in community after community.

Many communities have also proven that adequate street lighting can cut this high night rate down to daytime level.

In Detroit, where 31 miles of streets were relighted the ratio of night to day fatalities was cut from 7 to 1 to 1.1 to 1. In Hartford Connecticut the relighting of 27 miles of streets cut the traffic deaths from 37 to 5 a year.

Today, progressive communities across the country are preventing accidents—saving lives—by reducing night accident rates to the low day rates with Comfortable Seeing.

Your electrical utility is vitally interested in your community's welfare. They have the know-how to help you modernize your street lighting quickly on an economically sound, planned basis. They can call on General Electric's services for planning and consultation.

G-E street lighting equipment has the flexibility to give you Comfortable Seeing engineered to meet the specific needs of your community. *Apparatus Department, General Electric Company, Schenectady 5, New York.*

Let your electric utility street lighting engineer show you how comfortable seeing SAVES YOU FAR MORE THAN IT COSTS.

GENERAL ELECTRIC

YOU GET 4 EXCLUSIVE ADVANTAGES WHEN YOU SPECIFY

FLEUR·O·LIER

1 Only Fleur-O-Lier fixtures are rated on the Fleur-O-Lier Index Rating System. This gives illuminating characteristics, shielding, brightness, etc., for each fixture.

2 Complete photometric test data including distribution curves and coefficients of utilization tables are computed by Electrical Testing Laboratories, Inc., and are provided for every Fleur-O-Lier luminaire.

3 Fleur-O-Lier fixtures are *certified* by Electrical Testing Laboratories, Inc., as complying with rigid specifications covering electrical and mechanical construction.

4 More than 300 different Fleur-O-Lier fixtures made by nearly 30 manufacturers give you a wide selection from which to choose.

THESE 4 ADVANTAGES ASSURE *Lighting Satisfaction* WHEN YOU SPECIFY FLEUR-O-LIER

Free Booklet

Write for your free copy of the new booklet giving complete details of the Fleur-O-Lier Index System.

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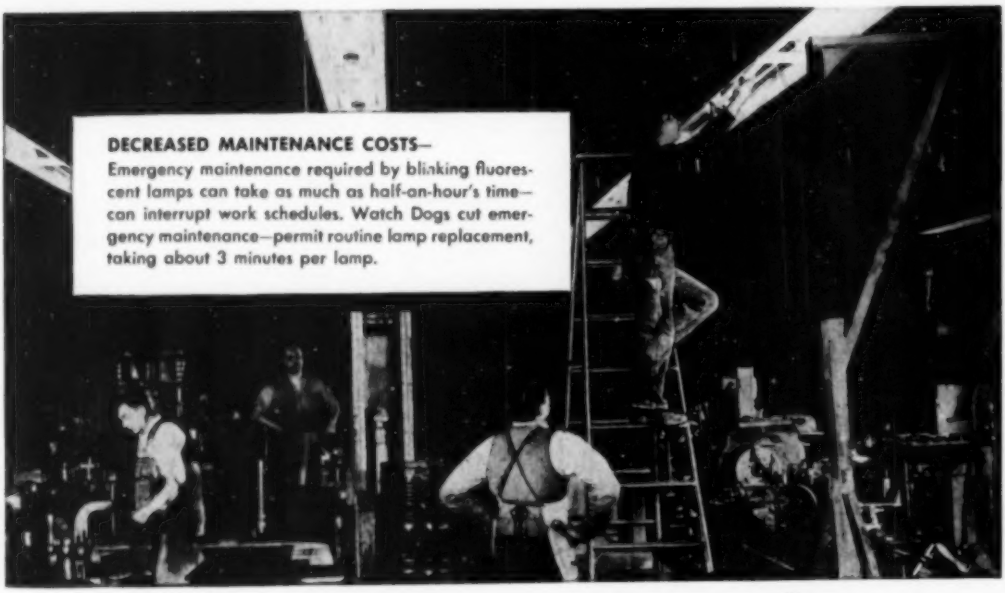
Fleur-O-Lier is not the name of an individual manufacturer but of a group of fixtures made by leading manufacturers. Participation in the Fleur-O-Lier program is open to any manufacturer who complies with Fleur-O-Lier requirements.

Let G-E *Watch Dog** starters cut your customers' maintenance costs

Whenever you make a recommendation, give your customers the benefit of low-maintenance fluorescent lighting—specify no-blink G-E Watch Dog starters.

Give every recommendation this low-cost extra for more comfortable seeing—for customer savings—for better customer relations.


DECREASED MAINTENANCE COSTS—
Emergency maintenance required by blinking fluorescent lamps can take as much as half-an-hour's time—can interrupt work schedules. Watch Dogs cut emergency maintenance—permit routine lamp replacement, taking about 3 minutes per lamp.

specify fixtures that display the Watch Dog label

The Watch Dog label and the famous red reset button are visible evidences of lower maintenance costs. They remind your customers, too, how Watch Dog's famous cut-out action means better fluorescent lighting. Section Q11-487, Construction Materials Division, General Electric Company, Bridgeport 2, Connecticut.

*Registered Trade-mark of General Electric Company

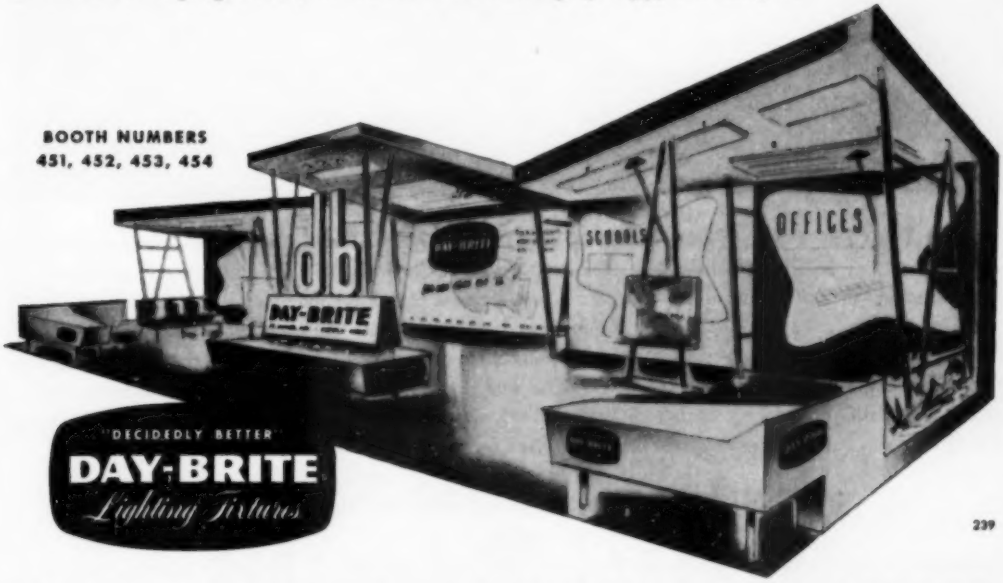
You can put your confidence in—

GENERAL ELECTRIC

This seal is to remind you that the biggest lighting event of the year will soon be held in Cleveland. The sketch below is to help you identify the one exhibit at the Lighting Exposition you won't want to miss.

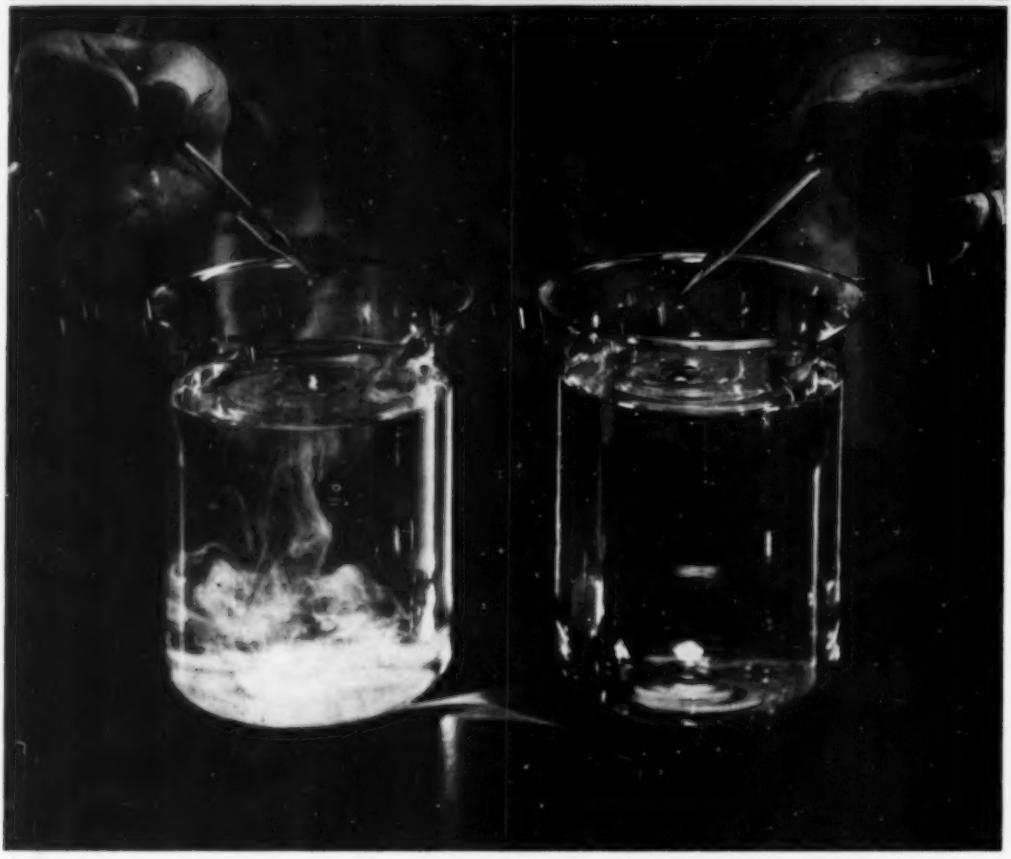
You are most cordially invited to visit the comfortable, colorful Day-Brite product parade — **featuring a complete new Day-Line® industrial line with narrower channel and 10% upward component . . . new, improved Derby Downlights . . . the first showing of new troffer enclosing elements and Plexoline® series with the most advanced shielding and low-brightness qualities.**

By all means, renew or begin your acquaintance with the nation's No. 1 line of lighting fixtures and the people who make them. We'll be mighty happy to have you.



DAY-BRITE LIGHTING, INC. • 5432 BULWER AVE. • ST. LOUIS 7, MO.

You should expect the best value from G-E fluorescent lamps



WATER TOO PURE TO DRINK HELPS GIVE YOU MORE LIGHT. It's the water on the *right* you wouldn't want to drink. It's so pure it's tasteless. You'd prefer the water on the left. Ordinary tap water, it's safe enough for drinking. But not for G-E fluorescent lamps. A chemical reagent shows mineral impurities. If they got into the phosphor coating, they would cut light output. On the glass tube, they would create a streaked look. So General Electric uses the specially ultra-deionized water shown at right in making our phosphors and to wash our lamp tubes. It's twice as free of minerals as distilled water. A small precaution—perhaps. But it helps give you more light and better looking lamps. You *should* expect the best value from G-E fluorescent lamps. This is another example of how far we go to make sure you can.

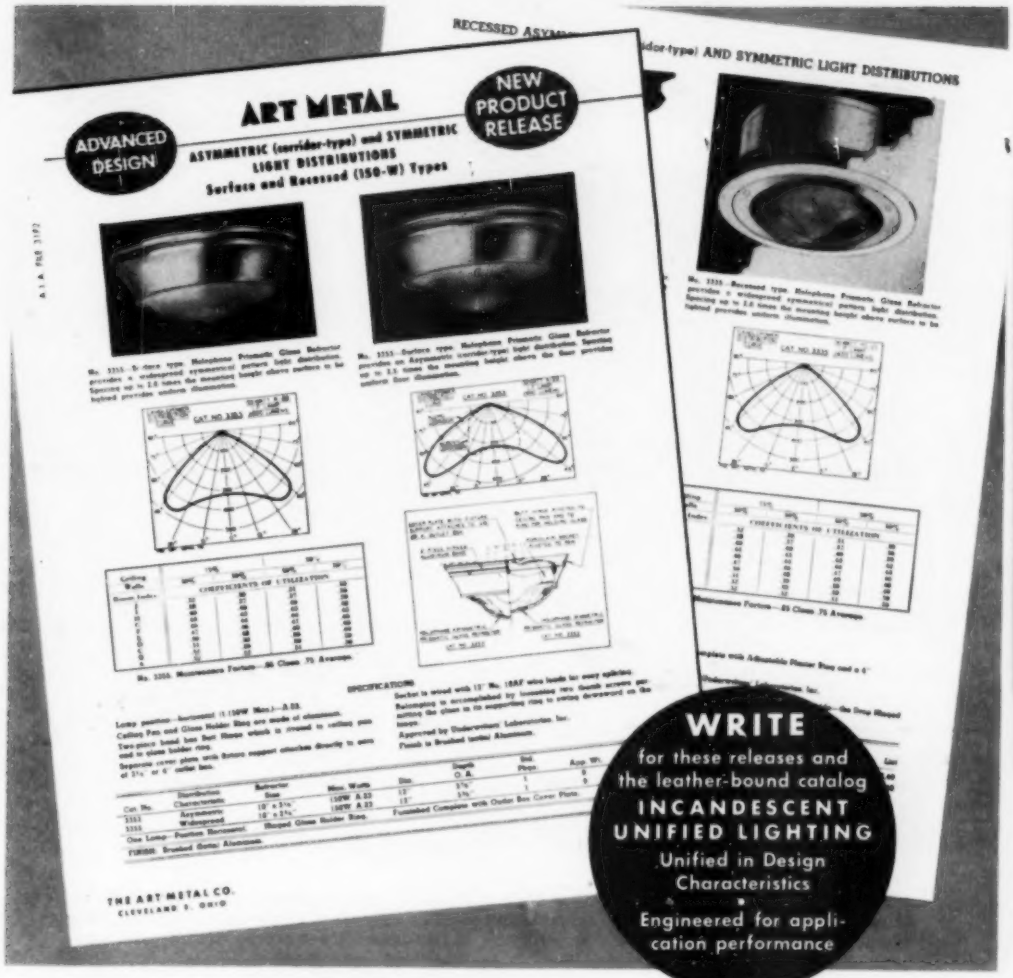
You can put your confidence in

GENERAL ELECTRIC

ART METAL releases

the SECOND of its NEW ideas in

INCANDESCENT LIGHTING

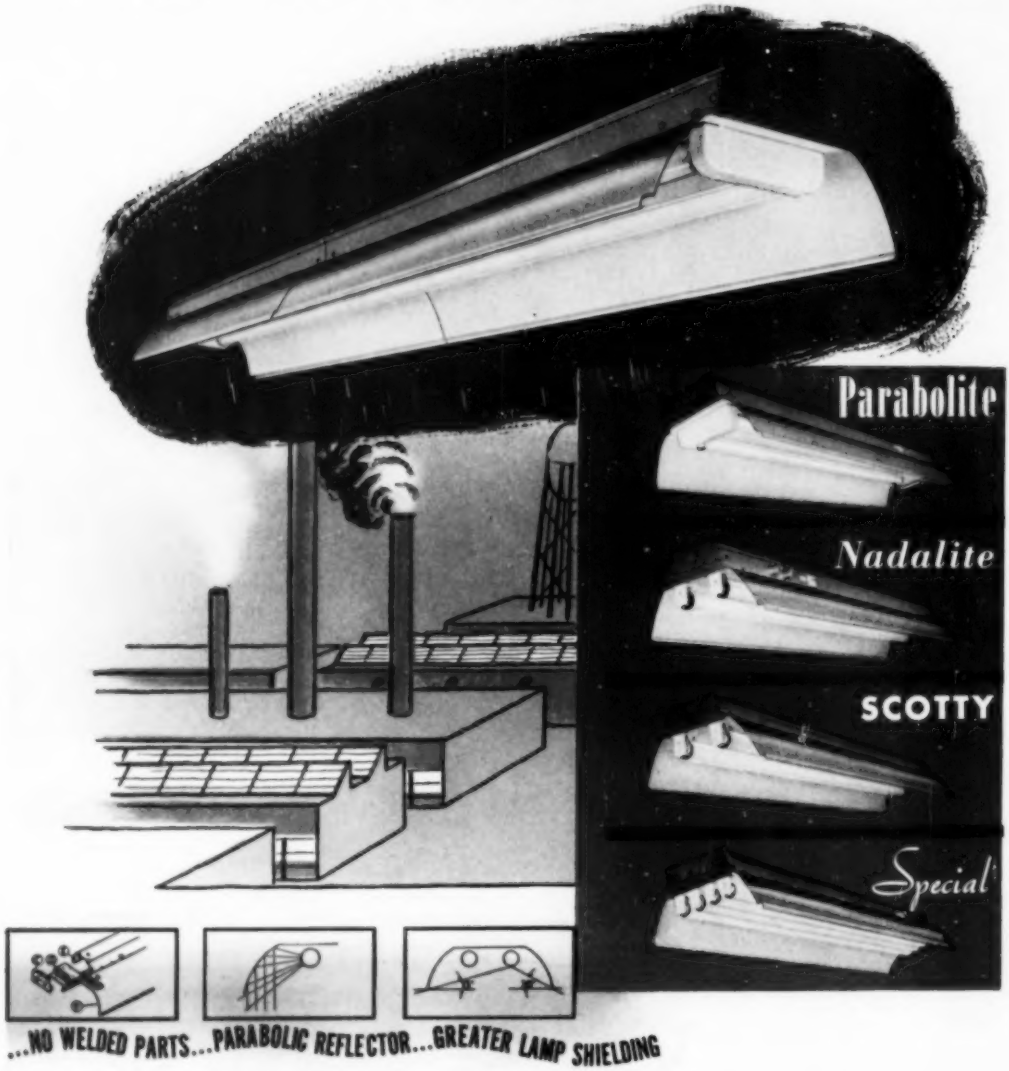


THE ART METAL COMPANY

CLEVELAND 3, OHIO

Manufacturers of Engineered Incandescent Lighting

a new line of Industrial fixtures!



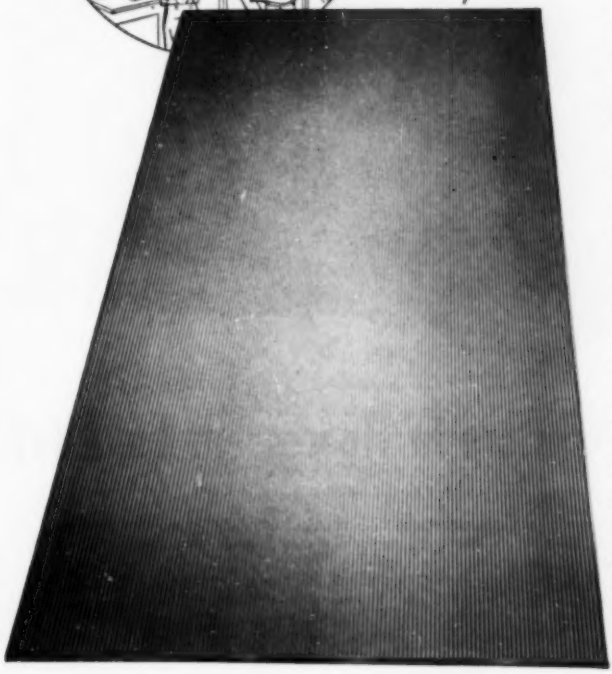
...NO WELDED PARTS...PARABOLIC REFLECTOR...GREATER LAMP SHIELDING

A complete new line of more than 150 models in three basic price ranges featuring parabolic reflector for maximum down light . . . normal lamp cut-off of 15°, which is in excess of all laboratory requirements . . . and toughest possible resistance to oxidation. There are no welded parts—sections are phosphatized and finished before being assembled with plated screws.

GIBSON Manufacturing Co. 1919 PIEDMONT CIRCLE, N. E., ATLANTA, GEORGIA

for excellent **FUNCTIONAL** *lighting . . .*

CORNING'S CRYSTA-LITE!



Good functional lighting directs maximum light into the working zone. Corning's CRYSTA-LITE prismatic lens panels do even more. Linear prisms eliminate high-level glare of fluorescent light by bending the high-angle rays downward into zones where they are most useful for illumination — giving you more light for seeing plus accurate brightness control.

Lightweight CRYSTA-LITE is made of water-white crystal glass and is not color selective. There is no distortion of the color source, making surroundings more pleasing . . . merchandise more appealing.

Especially suitable for long runs as well as individual fixtures, it is available in widths up to 24", lengths up to 100". CRYSTA-LITE may be obtained from leading fixture manufacturers, many of whom feature CRYSTA-LITE in their fixtures. For further details on all types of Corning engineered lightingware, send for Bulletin LS-32; Photometric sheets also available.

PYREX

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Corning means research in Glass

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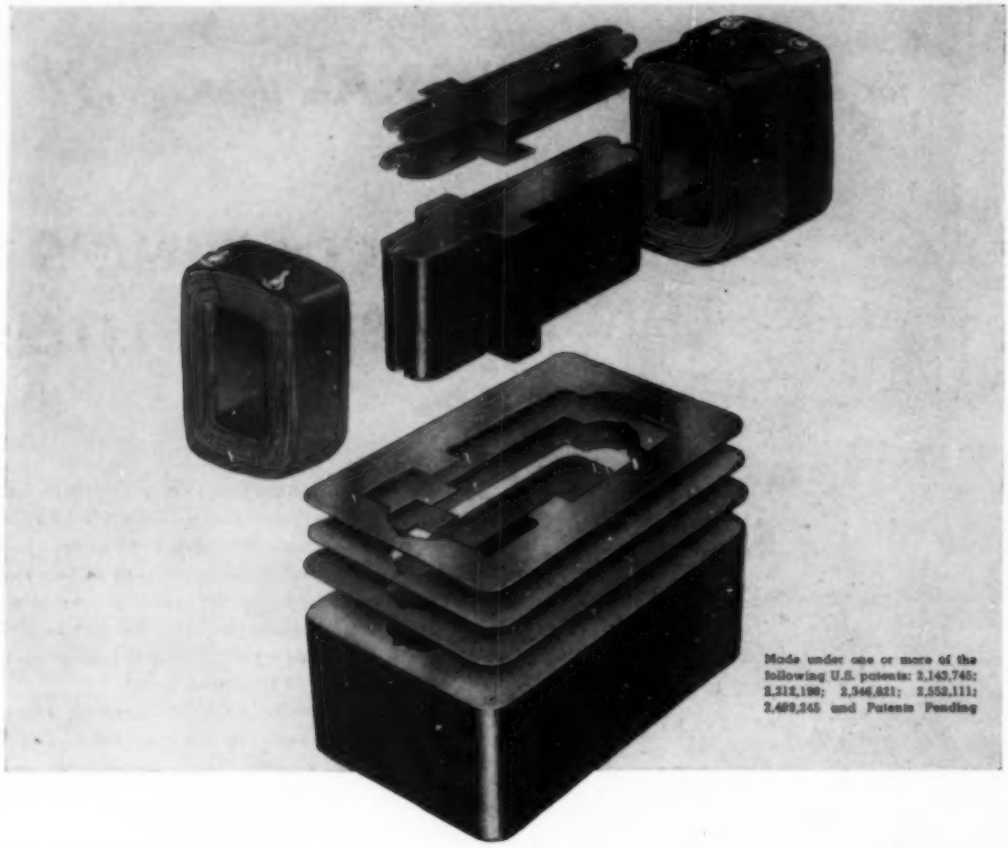

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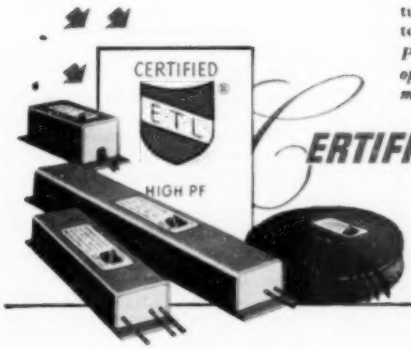

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INDEX TO ADVERTISERS
April 1952

Acme Electric Corp.	33A
Advance Transformer Co.	15A
Art Metal Co.	27A
Benjamin Electric Mfg. Co.	12A-13A
Certified Ballast Manufacturers	31A
Corning Glass Works	29A
Day-Brite Lighting Inc.	25A
Fleur-O-Lier Manufacturers	23A
General Electric Co., Apparatus	22A
General Electric Co., Const. Mat'ls.	24A
General Electric Co., Lamp	11A
Gibson Manufacturing Co.	28A
Edwin F. Guth Co.	18A-19A
4th Int'l. Lighting Exposition	21A
Jefferson Electric Co.	8A
Leader Electric Co.	20A
Litecontrol Corp.	26A
R.L.M. Standards Institute	Inside Back Cover
Radiant Lamp Corp.	32A
Rohm & Haas Co.	17A
Sola Electric Co.	30A
Sylvania Electric Products Inc.	34A
F. W. Wakefield Brass Co.	Inside Front Cover
Westinghouse Electric Corp., Lamps	Back Cover
Westinghouse Electric Corp., Lighting	1A

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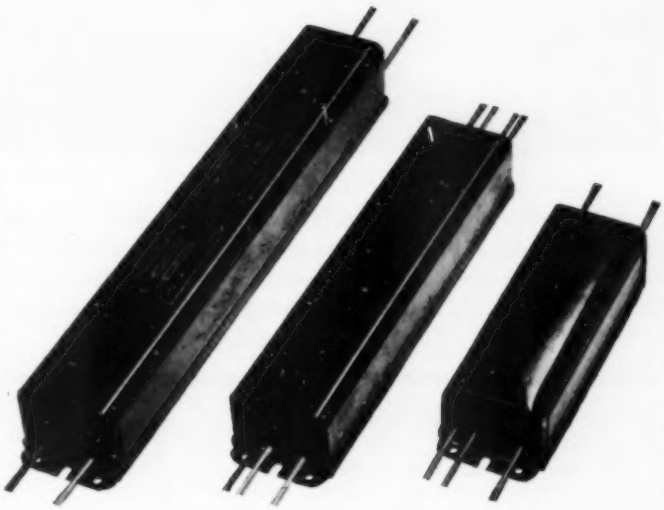

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